Farmer Nutrient Management Decisions: A Study of Farms in the Gully Creek Watershed in Southern Ontario

By

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ABSTRACT

FARMER NUTRIENT MANAGEMENT DECISIONS: A STUDY OF FARMS IN THE GULLY CREEK WATERSHED IN SOUTHER ONTARIO

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In Ontario there has been increased concern regarding harmful algae blooms in Lake Erie, phosphorus has been identified as the growth limiting agent. This research examines farmers' individual nutrient management decisions to understand if the actual nutrient application rates are equal to the recommended NMAN rate (N_E). I use two alternative nutrient rate criteria and a regression analysis to further examine nutrient application decisions. I use a unique data set from the Gully Creek watershed that contains farmers' individual nutrient application decisions for phosphorus and nitrogen, spanning 2008 to 2013. In corn production, farmers were found to apply nitrogen below the N_E, and phosphorus above the N_E. In winter wheat production, farmers were found to apply both nitrogen and phosphorus above the N_E. The regression analysis identified that larger farms, lower yielding fields, and the application of manure influence farmers' decisions to apply nutrients in excess of the N_E rate.

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Table of Contents

List of Figures

List of Tables

1. Chapter 1: Introduction and Research Motivations

Within in the Great Lakes region phosphorus has been identified as the growth limiting nutrient controlling the growth of harmful algae blooms (International Joint Commission, 2014). As such, phosphorus has become a focus in environmental management in Ontario. Identification and measurement of the of phosphorus pollution sources in surface water from agriculture is difficult due to the dispersed and diverse nature of cropland and associated drainage patterns (Carpenter *et al*. 1998; Dupont, 2010; Weersink and Livernois 1996). The adoption of specific emission-based policy has been successful in reducing pollution from identified sources (municipal sewage treatment facilities and industrial sources), but has been ineffective when addressing dispersed sources of pollution (Dupont, 2010; International Joint Commission, 2014).

Agricultural activities have a harmful effect on water quality in the Great Lakes region. Agricultural production, specifically field crop production, depends on the application of nutrients, both commercial fertilizer and manure, to supplement nitrogen, phosphorous, and potassium required for crop growth. However, farmer nutrient application may exceed the crop requirements, leading to excess nutrients in the soil and create potential for nutrients to enter surface water. These excess nutrients runoff into surface water, impacting surface water quality. Excess nutrients in surface waters have led to harmful algae blooms and ecological degradation including eutrophication in Lake Erie (International Joint Commission, 2014).

Farmers can be considered as individual economic agents, who seek to optimize their on-farm decisions regarding resource use (Dupont, 2010). The contamination of surface water by diffuse nutrient pollution from agriculture may not be accounted for by the individual farmer seeking to make the privately optimal decision of resource allocation. However, it should be noted that some farmers may account for the external effects of the actions on the surrounding environment, including the contamination of surface water with nutrients. Such surface water contamination imposes an external cost to society, due to the lost value associated with algae blooms and eutrophication, indicating a potential market failure. It should be taken into account that these externalities may also be linked to a non-market failure, and may, to some part, be derived externalities, the unintended side effect of government intervention (Brubaker, 2007; Wolf, 1979). The combination of the externality imposed by phosphorus pollution to surface water from agriculture and the difficulty associated with the identifying of the sources of pollution creates a challenging policy problem. Market-like incentives are either ineffective or difficult to design and enforce and do not result in the reduction of diffuse sources of nutrient pollution from agriculture (Dupont, 2010; Weersink and Livernois 1996).

Analyzing agricultural nutrient management from an economic perspective that considers agronomic factors can evaluate and shape policies and programs that effectively reduce excess nutrients in surface water, leading to improvements in water quality. These policies and programs may be used by federal, provincial governments and local watershed associations, conservation authorities, or environmental non-governmental organizations.

The majority of research focusing on decreasing excess nutrient loadings in surface water from agricultural sources has occurred outside of Canada. One area of research has focused on cost-effectiveness and the spatial distribution of beneficial management practices through a watershed as a means to reduce excess nutrients and improve water quality (Geng *et al*,2015; Gitau *et al.*, 2004; Panagopoulos *et al*, 2011). Limited research at the watershed scale has focused on understanding farmers’ nutrient application decision making. Stuart et al. (2014) examined social factors and information sources that influence farmers’ nutrient application decisions within a watershed in Michigan, collecting data through interviews and mail surveys.

This thesis will examine these factors in a Canadian context through the analysis of data collected through interviews within a watershed in Ontario.

1.1. Economic problem

In recent years, the Government of Ontario has become increasingly concerned with water pollution with nutrients (Dupont 2010; International Joint Commission, 2014). Decreased water quality in Lake Erie has been linked to algae blooms, imposing a number of costs to society. These costs to society include decreased water quality, impacting drinking water supply, decreased recreation value, and ecological impacts including decreased water oxygen levels causing fish kill and eutrophication risk. Phosphorus has been identified as a growth limiting factor for algae in Lake Erie (International Joint Commission, 2014). A number of sources of phosphorus impacting surface water have been recognized in the Great Lakes region, and phosphorus from agricultural sources has been identified as a source of concern (International Joint Commission, 2014). Regulators such as the Ministry of the Environment and Climate Change (MOECC), the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and conservation authorities are all instrumental in determining what the socially optimal pollution level is, while ensuring that a farmers' nutrient application decisions ensure financial viability of the farming operation.

1.2. Economic Research Problem

Field crop farming in the Great Lakes region has been identified as a significant source of phosphorus (International Joint Commission, 2014). Nutrients are required in field cropping systems to meet crop requirements for production. Nutrients from field cropping systems can enter surface water through runoff when applied in excess of the crop requirements. Field cropping farmers, however, generally do not meet the thresholds that lead to regulation under that Act. Nevertheless, crop nutrient decisions by crop farmers may, in situations where nutrients are applied in excess of crop requirements, contribute to reduced water quality. At present, there is limited information about the decision criteria that Ontario crop farmers apply in making crop nutrient decisions. Consequently, developing approaches to curb excess nutrient application in field crop production is difficult. Identifying and understanding the factors that influence these cropping farmers' nutrient application decisions will enable OMAFRA, the MOECC, conservation authorities, agronomists and environmental scientist to address the issue of harmful algae blooms in Lake Erie.

I selected the Gully Creek watershed, a 14.3 km^2 sub-watershed of the Bayfield North watershed in Huron County, as the study site. The Gully Creek watershed empties in to Lake Huron, which in turn empties to the south into Lake St. Clair through the St. Clair River. Lake St. Clair has a short hydraulic retention time, water flows through the Lake and into Lake Erie in 9 days (Lang, Morton and Fontaine, 1988). I examine the factors that influence farmers' nutrient application decisions to apply excess nutrients which can enter surface water and impact water quality in Lake Erie.

1.3. Objectives

The purpose of this research study is to understand the factors that influence farmer's nutrient application decisions. To do this, the study has the following objectives:

I. To review the agronomic foundation of nutrient use in Ontario agriculture and the history of international joint agreements targeting surface water quality between Canada and the United States;

II. To document how farmers are making their nutrient application decisions by analyzing farmer nutrient application behavior in the Gully Creek watershed spanning a six-year period, from 2008-2013;

III. To evaluate the use of Ontario’s criminal code to enforce the Nutrient Management Act as a tool to decrease nutrient loadings in the Great Lake region;

IV. To outline the implications of this research to OMAFRA, conservation authorities, environmental economists, agronomists and environmental scientists by discussing the findings of the empirical analysis of the Gully Creek watershed.

1.4. Thesis Organization

The thesis is organized as follows. Chapter 2 outlines nutrient loadings in the Great Lakes region, nutrient use in agriculture, relevant international agreements and policy targeting decreasing nutrient loadings in the Great Lake region. Chapter 3 contains the case study of the Gully Creek watershed, analyzing farmer’s nutrient application decisions. Chapter 4 develops the analysis of the Nutrient Management Act as a compliance tool to decrease excess nutrient application in agriculture, discussing the social welfare problem. Finally, Chapter 5 summarizes the conclusions of this thesis, discussing the limitations, implications and suggestions for future research.

2. Chapter 2: Nutrient Use in Ontario and Great Lakes Water Quality

This chapter reviews the physical processes through which excessive agricultural nutrients can find their way into water bodies like Lake Erie. It also reviews the various policy measures that have been taken in recent years to address water quality problems in the Great Lakes.

2.1. Introduction

Of the Great Lakes, Lake Erie has been identified as the most susceptible to harmful algae blooms (Steffen *et al.*, 2014). Historically, harmful algae blooms have been observed in Lake Erie since 1959 (Beeton, 1963; International Joint Commission, 2014). By the 1960s, the algae blooms had become the focus of scientists, the United States and Canadian Governments and public concern (Steffen *et al.*, 2014). The economic impacts of harmful algae blooms include decreased environmental quality, causing fish kill-offs, decreased recreational value and risk to human health due to toxicity of the algae (International Join Commission, 2014). Policy interventions through the 1970s effectively decreased the occurrence of algae blooms in Lake Erie until 1995 (Steffen *et al.*, 2014). The phytoplankton *Microcystin,* identified as the most abundant cyanobacteria (algae) in Lake Erie, is toxic to human beings and other species. Concentrations greater than 1 μg/L are deemed unsafe for human consumption by the World Health Organization (Steffen *et al.*, 2014). In 1995, an increasing concentration of *Microcystin* was detected in Lake Erie (>1 μg/L), increasing to concentrations unsafe for human consumption in 2001 (238.81 μg/L) (Figure 1) (Steffen *et al.*, 2014). The reported maximum concentrations of *Microcystin* varies greatly across years, likely due to the spatial and temporal difference in sampling, and the fact that samples are often collected outside the actual bloom (Steffen *et al.*, 2014).

In the Great Lakes region phosphorus has been found to be the growth limiting nutrient in the case of algal blooms (Dolan, 1993; International Joint Commission, 2014). The concentration of nitrogen in surface water in the Great Lakes region that is naturally present is sufficient concentrations to support algae growth (International Joint Commission, 2014; Lake Erie Nutrient Scientific Task Group, 2009). The international nature of the phosphorus loading in Lake Erie and the share jurisdiction across federal, state and provincial agencies for the of the monitoring of phosphorus concentrations in the basin of Lake Erie makes it difficult to access information. Figure 2 reports the total annual loading of phosphorus in metric tons and is an estimate from a model created by Dolan and Chapra (2012). Policy targeting nutrients in the Great Lakes region has focused on decreasing phosphorus concentrations in an effort to decrease harmful algae blooms.

The historical policy targeting nutrients for phosphorus in the Great Lakes region focused on easily identifiable sources of pollution, including municipal sewage treatment plants and industrial sources, referred to as direct point sources in literature, (International Joint Commission, 2014). More recent policy has begun to focus on less easily identifiable sources, referred to as non-point sources (NPS) in literature. These less easily identifiable sources include the agricultural field application of nutrients (commercial fertilizer and manure), paved urban areas and atmospheric deposition (International Joint Commission, 2014).

Algae, being a biological organism, is the subject of study and monitoring of biologists and environmental scientists, and likely falls under the responsibility of a different agency or research group than the monitoring of phosphorus loadings. The monitoring of phosphorus loadings, linked to hydrological modeling, is the subject of study of environmental engineers, hydrologist, chemists and physical geographers. The interdisciplinary nature of the problem of harmful algae blooms requires different agencies and research groups to communicate and collaborate. Collecting information from these different disciplines, which use different metrics and procedures in monitoring, means that interpreting results can be challenging. Phosphorus was first identified as the growth limiting factor for harmful algae blooms in Lake Erie in the 1960s. Given the number of factors that influence algae blooms in Lake Erie, it is possible that phosphorus in no longer the growth limiting factor.

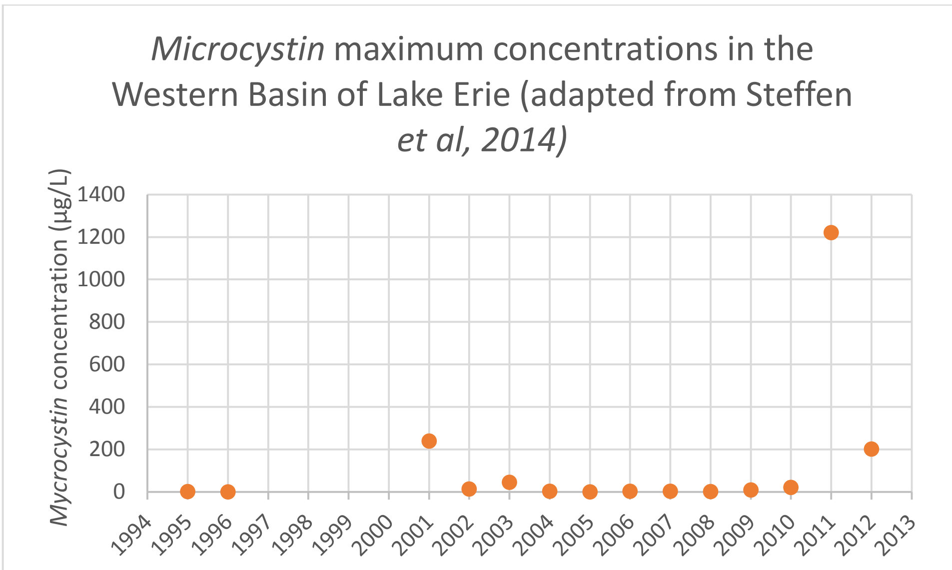

Figure 1: Microcystin Concentrations in the Western Basin of Lake Erie 1995 – 2012

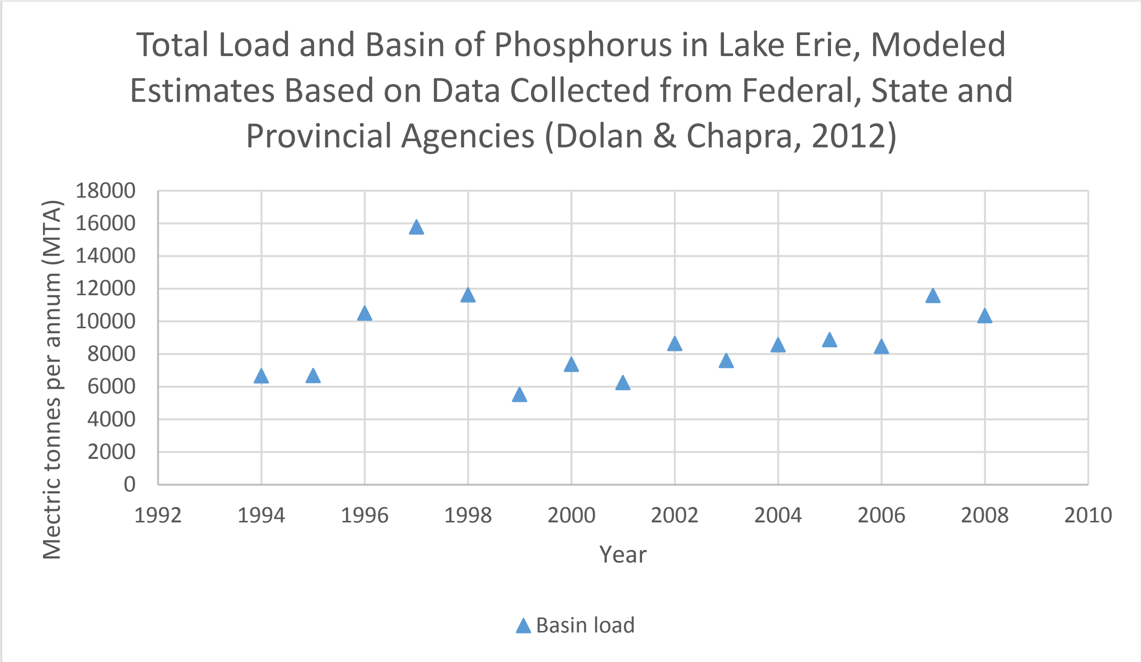

Figure 2: Total Basin Load on an Annual Basis of Phosphorus Loadings in the Basin of Lake Erie from 1994 to 2008, Estimated Using Data Collected from Federal, State and Provincial Agencies

2.2. Nutrient Transportation Mechanism to Surface Water

Nutrients can enter surface water by four mechanisms: water erosion, wind erosion, groundwater and atmospheric deposition (International Joint Commission, 2014; OMAFRA, 2011). In the Great Lakes region, water erosion and wind erosion account for the majority of nutrients entering surface water (International Joint Commission, 2014). Water erosion moves particulate nutrients from the soil surface through runoff. Runoff can remove both dissolved nutrients as well as nutrients bound to soil particles (sediment). The majority of phosphorus entering surface water through runoff is bound to sediment, specifically small soil particles such as clay (Blanco & Lal, 2008). Whereas the majority of nitrogen entering surface water through runoff is soluble and is dissolved in the water running along the soil surface (Thomas *et al*, 2011).

Wind erosion removes soil particles containing nutrients from exposed and dry soils (OMAFRA, 2011). The majority of the soil particles removed by wind erosion are deposited in surrounding fields or structures used to prevent wind erosion such as windbreaks. If the fields subjected to wind erosion are adjacent to bodies of surface water, deposition of some of the nutrient containing particles may occur, leading to surface water pollution, this is a form of atmospheric source (International Joint Commission, 2014; OMAFRA, 2011). Precipitation is an additional source of atmospheric deposition (International Joint Commission, 2014).

In the case of phosphorus, upon entering the surface water, a small percentage of the phosphorous is immediately soluble and available to aquatic plant species such as algae (Pierzynski, Sims & Vance, 2000). The soluble phosphorus in surface water is referred to as the total dissolved phosphorus (TDP), which is composed of the soluble orthophosphate and some dissolved organic phosphorus (OMAFRA, 2011). The sediment bound phosphorus in surface water is referred to as particulate phosphorus (PP) and is deposited on the lake or river bottom, unavailable unless turbulence or depletion of TDP occurs (OMAFRA, 2011; Pierzynski, Sims & Vance, 2000). PP is composed of the stable phosphorus compounds bound to calcium, iron and aluminum, phosphorus bound to soil particles and insoluble organic phosphorus (OMAFRA, 2011). Climatic conditions cause turbulence in water bodies and disturb the sediment, suspending particles in the water where aquatic plant species, such as algae, can access the PP (Pierzynski, Sims & Vance, 2000). All the phosphorus available to aquatic plant species, including algae, is referred to as the bioavailable phosphorus (BAP). BAP is all the TDP and a small percentage of the PP, depending on water turbulence and particle suspension (OMAFRA, 2011; Pierzynski, Sims & Vance, 2000).

Nitrogen entering surface water is primarily in the mineralized form of nitrate (NO_3^-), highly soluble in water, loosely held by soil particles and immediately available to aquatic plant species such as algae (OMAFRA, 2016; Thomas *et al.* 2011). Nitrate enters surface water when the soil is saturated and the excess water can no longer be absorbed by the soil, which occurs during high levels of rainfall or snow melt (OMAFRA, 2016). Small concentrations of nitrogen enter surface water bound to soil particles in the form of ammonia (NH_4^+), which is unavailable to aquatic plant species, including algae (OMAFRA, 2016). Ammonia, if converted into sufficient concentrations of un-ionized ammonium (NH_3^+), while unavailable to algae, causes environmental damages, harming aquatic organisms including fish (Canadian Water Quality Guidelines for the Protection of Aquatic Life, 2010).

2.3. Nutrients in Agriculture

Nutrients in crop production are traditionally divided into three categories: macronutrients, secondary nutrients and micronutrients (OMAFRA, 2006). Insufficient levels of any nutrient can limit crop growth and yields. The micronutrients in the soil are boron, copper, iron, manganese, molybdenum and zinc. The secondary nutrients in soil are calcium, magnesium and sulfur. The macronutrients in the soil are nitrogen, phosphorus and potassium, more commonly referred to as N-P-K, all three of which are necessary in relatively high concentrations for crop production. Modern Canadian agriculture relies on mineral fertilizers to address soil fertility issues and maintain agricultural production. The application of mineral fertilizers to agricultural soils is intended to "improve and maintain soil fertility" with the intention of using soil as a medium for crop growth (OMAFRA, 2015).

2.3.1. Nitrogen Fertilizers

Commercial nitrogen fertilizer is created using the Haber-Bosch Process to create ammonia (NH_4^+) (Brady & Weil, 2009; Thomas *et al.* 2011**)**. The Haber-Bosch Process is energy intensive, requiring natural gas and atmospheric nitrogen for the production of ammonia.

Ammonia is used as the feedstock for nitrogen fertilizer production. Common forms of nitrogen fertilizer include anhydrous ammonia nitrate (NH_4NO_3) and urea ($CO(NH_2)_2$). Nitrogen is required by plants for many essential processes including growth, protein formation and chlorophyll production (OMAFRA, 2006). Severe nitrogen deficiencies can lead to stunting, decreases in yield and reduced protein content of grain (OMAFRA, 2006). Excess concentrations of nitrogen in the soil can promote rapid and lush plant growth, increasing the likelihood of disease as well as the depletion of other essential nutrients in the soil (OMAFRA, 2006). Nitrogen pollution from agricultural soils can occur through leaching, erosion and runoff (Pierzynski, Sims & Vance, 2000). The leaching of nitrogen to groundwater aquifers is a concern in sandy, well drained soils as it leads to groundwater contamination with nitrate and is a concern over future viability for drinking water (Blanco & Lal, 2008). Whereas the pollution of surface water with nitrogen occurs primarily through runoff, removing soluble organic and inorganic nitrogen (Blanco & Lal, 2008).

The majority of nitrogen in soil is composed of soil organic matter and plant matter (95%) and is unavailable to crops (Thomas *et al.* 2011). Mineralization of this organic nitrogen (to ammonium NH_4^+) by soil micro-organisms occurs naturally in the soil nitrogen process, creating inorganic nitrogen that is available to crops. The mineralized form of nitrogen (NH_4^+) binds to soil particles, and enter surface water bound to these soil particles through wind erosion and water erosion, primarily runoff. Ammonium can be further mineralized by soil micro-organisms to nitrate (NO_3^-) that is not closely bound by soil particles and is easily dissolved in water and susceptible to removal by water, both through runoff and leaching (Killpack & Buchholz, 2015). The main sources of nitrogen in soil are atmospheric deposition, bacterial fixation, manure, plant matter and commercial fertilizers, and of these sources, only commercial nitrogen fertilizer contains high concentrations of mineralized nitrogen immediately available to crops (Thomas *et al.* 2011).

2.3.2. Potassium Fertilizer

The common commercial potassium fertilizer is the muriate of potash, which is chemically potassium chloride (KCl) (Brady & Weil, 2009; Thomas *et al.* 2011**)**. Potassium is essential in crop growth for enzyme activation and remains unbound within the organic structures of the crop. Potassium chloride is soluble in water and the most mobile of the three soil macronutrients. The applications of potassium fertilizer high rates can lead to salt damage in crops. Potassium does not pollute the environment once it has left the soil, unlike phosphorus and nitrogen (Brady & Weil, 2009). Potassium neither contributes to eutrophication or environmental toxicity (Brady & Weil, 2009).

2.3.3. Phosphorus Fertilizer

The common commercial process used to produce phosphorus fertilizer involves washing rocks containing phosphorus with sulphuric acid to increase soluble phosphorus salts (Brady & Weil, 2009; Thomas *et al.* 2011**)**. Fertilizers containing phosphorus, regardless of the chemical form, are measured in terms of phosphate (P_2O_5). The most common form of phosphorus fertilizer from this process is triple superphosphate $(Ca(H_2PO_4)_2)$. Additional forms of phosphate fertilizer can be created using the nitrophosphate or Odda process. Fertilizers created using the Odda process contain both nitrogen and phosphorus. Common forms include: monoammonium phosphate $(NH_4H_2PO_4)$ and diammonium phosphate $((NH_4)_2PO_4)$. Commercial chemical phosphorus fertilizer is both available to crops and highly soluble in water. The high solubility of phosphorus increases the potential for contamination of water bodies with phosphorus (Blanco & Lal, 2009).

The majority of phosphorus in soil is unavailable to crops (Blanco & Lal, 2009). Crops can absorb phosphorus most easily in it ionic form: $H_2PO_4^-$ in acidic soils (pH less than 7) and HPO_4^{2-} in alkali soils (pH greater than 7) . Directly in the root zone, some forms of organic phosphorus are available to crops. Ionic and phosphorus and organic phosphorus compounds account for less than 0.01% of the total phosphorus in the soil. The availability of phosphorus in soil is related to the pH of the soil. Highly acidic or alkali soils phosphorus is not highly soluble. The maximum solubility (and availability to plants) occurs between a pH of 6.0 and 7.0.

Soil does not naturally contain high concentrations of phosphorus. In nature, the major transfers of phosphorus in soil occur due to tectonic plate movement (Schlesinger & Bernhardt, 2013). Unlike nitrogen, there is little atmospheric deposit or fixation of phosphorus. Phosphorus in soil is divided into three pools: soluble, labile and stable (OMAFRA, 2011). Soluble phosphorus is the pool of phosphorus primarily in orthophosphate form which is readily available to plants (OMAFRA, 2011). Labile phosphorus is both organic and inorganic phosphorus that is loosely held by soil particles, and after depletion of the soluble phosphorus, can become available to crops (OMAFRA, 2011). Stable phosphorus is both organic and inorganic phosphorus which is tightly bound to soil particles by aluminum, iron and calcium, depending on soil pH, and is unavailable to crops (OMAFRA, 2011; Pierzynski, Sims & Vance, 2000). The application of mineral phosphorus fertilizer in modern agriculture is intended to maintain sufficient phosphorus concentrations to prevent the occurrence of growth inhibiting phosphorus deficiencies in crops (OMAFRA, 2006). Crops require phosphorus for the development of roots, flowers, seeds and fruits. Phosphorus deficiencies in crops can be difficult to diagnose without a soil nutrient test due to the lack of distinct symptoms. Typical symptoms in fields crops include stunting and in extreme cases purpling of the leaf margins.

Of the phosphorus fertilizer applied to the soil, crops will only use up to 30% of the soluble phosphorus (OMAFRA, 2006). The unused fertilizer has a residual value and can build up in soil overtime (OMAFRA, 2006). The continual annual application of mineral phosphorus fertilizer has, in many regions, lead to increased soil phosphorus concentrations beyond the requirements for crop production. This increase in soil phosphorus concentration is a concern to policy makers, farmers and the public due to the potential for increased water pollution with phosphorus from the soil.

2.3.3. Manure Fertilizer

Manure is commonly used as a source of nutrients in agriculture as it contains all the nutrients required for crop growth, as well as secondary nutrients, organic matter that maintain soil health (OMAFRA, 2016b). The nutrients in manure, nitrogen and phosphorus, are not always available in the concentrations or proportions required for crop growth, meaning that the farmer may need to apply chemical fertilizer to meet the crop requirements (OMAFRA, 2016b). The specific nutrient content of the manure is variable. A study in Ontario found the mean nutrient concentrations and standard deviations for a 24 sample set of poultry manure (Afum, 2014). The mean nitrogen concentration and standard deviation of the sample was 40.1 kg/metric ton and 18.1 kg/ metric ton (Afum, 2014). The mean phosphorus concentration and standard deviation of the sample was 16.7 kg/ metric ton and 7.8 kg/ metric ton (Afum, 2014). The standard deviation of both nitrogen and phosphorus captures the variability of the nutrient content of manure. This variability may lead to farmer reliance on chemical fertilizer, even in combination with manure, to meet crop nutrient requirements.

2.4. Non-Agricultural Nutrients

Within the Great Lakes region, in addition to agriculture, urban and atmospheric deposition have been identified as sources of nutrient loadings (International Joint Commission, 2014). Urban sources include waste water treatment facilities, construction sites, storm water runoff and yard/garden activities (International Joint Commission, 2014). The majority of urban sources of nutrients are identifiable, where a specific source of the nutrient loading can be located and effectively dealt with. Nutrient loadings from these identified sources have decreased through the last 40 years, from approximately 5500 metric ton/year in 1975 to 1000 metric ton/year in 2011 (International Joint Commission, 2014). However, significant nutrient loadings from urban areas still occur in wet weather (heavy rain and snowmelt), when bypass of waste water treatment facilities occurs (International Joint Commission, 2014).

Atmospheric deposition, the movement of nutrients from the air-shed to the biosphere or watershed, accounted for approximately 6% of the phosphorus loadings into Lake Erie in 2011 (International Joint Commission, 2014). Nutrients can move from the air-shed to the watershed through two primary mechanisms, precipitation containing nutrients (wet-deposition) and particulates containing nutrients (dry-deposition) (International Joint Commission, 2014). Both wet and dry-deposition of nutrients are linked to anthropogenic activities including combustion (of biomass and oil), agriculture, decomposition of sewage, landfill and compost, and coal burning (International Joint Commission, 2014).

2.5. Review of Agreements and Policies Targeting Nutrients in the Great Lakes Region

This section provides an overview of policies and agreements governing the management of water resources in the Great Lakes region from 1909 to 2015. These agreements and policies involve the Canadian federal and provincial governments, as well as United States federal and state governments responding to environmental indicators in the Great Lakes region. Figure 3 illustrates the timeline of algae blooms in Lake Erie and the resulting agreements in the Great Lakes region.

Figure 3: Timeline of Algae Blooms in Lake Erie and Joint International Agreements

2.5.1. Boundary Waters Treaty

The Great Lakes region has been subject to joint policy initiatives between the Canadian and United States governments beginning in 1909 with the Boundary Water Treaty. Canada, a dominion of the British Crown, and the United States negotiated the treaty in response to conflicts associated with water use (Harrison, 2008). The Boundary Water Treaty contributed to the management of water quality in the Great Lakes region by creating the International Joint Commission, an organization responsible regulation of shared water use and the investigation of transboundary issues and the recommendations of solutions (International Joint Commission, 2016). Additionally, the Boundary Water Treaty provided the first legal framework to prevent and resolve disputes between Canada and the United States over boundary waters (International Joint Commission, 2008).

2.5.2. Great Lakes Water Quality Agreement 1972, 1978

Phosphorus loadings in the Great Lakes became a public concern in the 1960s (International Joint Commission, 2013). Eutrophication, specifically oxygen depletion resulting from algae blooms, in the Great Lakes through the 1960s and early 1970s was subject to intensive investigation leading to changes in wastewater policy, specifically the Great Lakes Water Quality Agreement (GLWQA). In 1972 the first iteration of the GLWQA was signed by both Canada and the United States. The GLWQA (1972) specified allowable concentration of phosphorus from municipal wastewater discharges (Environment Canada, 2013). The International Joint Commission conducted research and presented recommendations to address the issue of phosphorus pollution in the Great Lakes region in the first GLWQA (International Joint Commission, 2015). The GLWQA (1972) focused on decreasing easily identifiable sources of phosphorus pollution in the Great Lakes region. In 1978 the GLWQA was revised to include the management of other nutrients of concern, control the release of toxins and broadened to encompass an ecosystem approach (Environment Canada, 2013).

2.5.3. Great Lakes Water Quality Agreement 1987

Monitoring of phosphorus levels in Lake Erie indicated that the GLWQA was successful in decreasing phosphorus pollution in the Great Lakes through the late 1970s and early 1980s (International Joint Commission, 2014). The 1987 GLWQA resulted in the creation of the Great Lakes Action Plan Phase I, effective from 1989-1994 (Environment Canada, 2013). The aim of the Great Lakes Action Plan was to maintain the sustainability of the Great Lakes ecosystems as well as funding programs and initiatives under the GLWQA and the Canadian Federal Great Lakes Program (Environment Canada, 2013).

Through the late 1980s, estimated total phosphorus loadings, calculated using models based on water sampling data collected from federal, state and provincial state agencies, in the Great Lakes, specifically Lake Erie, varied considerably (Dolan, 1993; Dolan & Chapra, 2012; International Joint Commission, 2014). In 1984 the estimated annual phosphorus load was approximately 12,500 metric ton/year and decreased to 7,500 metric ton/year in 1988 (Dolan & Chapra, 2012; International Joint Commission, 2014). The annual variation between 1986 and 1990 was demonstrated to be linked not to municipal sources, but to phosphorus entering Lake Erie through its surrounding watershed and tributaries from dispersed sources (Dolan, 1993). The levels of phosphorus entering Lake Erie through these watersheds and tributaries was linked to the wetness (annual rainfall) of the year (Dolan, 1993). The greater the level of precipitation in the year, the greater run off and greater the loading of phosphorus in Lake Erie (Dolan, 1993).

2.5.4. Great Lakes Water Quality Agreement 2012

In the 2000 biennial report on Great Lakes water quality, published by the International Joint Commission, expressed concern over the effects several factors including phosphorus contaminated sediment (International Joint Commission, 2000). Phosphorus has again become a concern in the Great Lakes region due to recent algae blooms in Lake Erie, as demonstrated in Figure 2. This has imposed a number of costs to society, including beach closures and issues associated with drinking water quality (van Bochove *et al.* 2006). Nutrient management plans in Ontario and Quebec already specify agricultural management practices to reduce pollution to surface water (van Bochove *et al.* 2006). Unlike previous algae blooms Lake Erie, the identification of the specific sources of phosphorus has been an issue (Environment Canada, 2012). Increased temperatures, light penetration, phosphorus pollution and pathways in the lakes are factors that all influence algae growth. However, of these factors influencing algae growth, only phosphorus pollution can be anthropogenically controlled. Phosphorus was first identified as the growth limiting factor in the 1960s, further research to confirm that phosphorus is still the growth limiting factor is required. Identification and measurement of the of phosphorus pollution sources in surface water from agriculture is difficult due to the dispersed and diverse nature of cropland and associated drainage patterns hence the enigmatic but common “non-point source” (Carpenter *et al*. 1998; Dupont, 2010; Weersink and Livernois 1996). To address these concerns the GLWQA agreement was further amended by the Canadian and United States Governments in 2012.

The 2012 amendment is the GLWQA outlining the current objectives and goals. It has been expanded to address additional environmental issues including climate change, aquatic invasive species and habitat and species (Environment Canada, 2013). The 2012 amendment of the

GLWQA incorporates changes in environmental management and knowledge of aquatic processes gained since the GLWQA (1987) amendment (Environment Canada, 2013). With regards to phosphorus pollution in the Great Lakes the GLWQA (2012) amendment specifies both short term and long term goals and actions. The actions specific to phosphorus in the GLWQA (2012) are:

- The development of specific objectives for phosphorus concentrations, loading targets as well as loading allocations in Lake Erie by 2015;
- The development of phosphorus reduction strategies by 2017 to meet the objectives specified in the previous action;
- The evaluation, development and implementation of management plans to decrease phosphorus pollution from municipal, industrial and agricultural sources;
- The identification of watersheds contributing to algae blooms and develop and implement management plans to decrease phosphorus loading goals;
- Establish collaborative research, monitoring and modeling to evaluate the effectiveness phosphorus management initiatives as well as other nutrients associated with algae blooms in the Great Lakes region (Environment Canada, 2013A).

Canadian Environmental Protection Act (1999) enables the Minister to release enforceable guidelines to address the issue of marine pollution from land-based sources, including agriculture (Justice Laws Website, 2015). These guidelines are released after consultation with other affected Ministers.

2.5.5. Western Basin of Lake Erie Collaborative Agreement 2015

In response to the increasing severity and occurrence of the algae blooms in Lake Erie, the province of Ontario and the states of Ohio and Michigan agreed upon the Western Basin of

Lake Erie Collaborative Agreement (2015) (CGLSLGP, 2015). The Western Basin of Lake Erie Collaborative Agreement acknowledges the importance of the Western Basin of Lake Erie and the health of the lake as a whole, impacting the social and economic welfare of both the States and Province (CGLSLGP, 2015). The Agreement acknowledges the collaborative effort required between the States and Province to meet the target of reducing phosphorus loadings by 40% of 2008 levels by 2025, with an interim goal of 20% by 2020 (CGLSLGP, 2015). The Agreement requires each party to create an implementation plan, engaging with stakeholders, to create an outline of the proposed timelines and actions towards meeting the reduced phosphorus targets by 2020 and 2025 (CGLSLGP, 2015).

Stemming from these agreements, and given the joint jurisdiction of agriculture shared by the federal government of Canada and the provincial government of Ontario, regulatory and incentive based policy programs have been developed by both the federal and provincial governments aimed at decreasing nutrient loadings from agriculture in the Great Lakes region.

2.5.6. Incentive Based Policy

The Canada-Ontario Environmental Farm Plan is an example of cost-sharing (incentive) based voluntary program aimed at reducing the environmental impacts of agriculture (Brouwer *et al.*, 2012; Government of Canada & Government of Ontario, 2015). The Environmental Farm Plan program began in at the pilot scale in 1993, by 1997 it was a national program Agriculture and Agri-Food Canada, and in 2005 the program was jointly funded by Agriculture and Agri-Food Canada and OMAFRA (OMAFRA, 2016a). The Environmental Farm Plan program requires participants to attend two workshops, the first workshop assists participants identify areas of concern, and the second workshop assists participants in identifying actions to address areas of concern and how to create a realistic Action Plan (Brouwer *et al.*, 2012). Participation is voluntary, farmers can opt-out of the program at any point through the process (Brouwer *et al.*, 2012). The next step in the process requires participants to develop an Action Plan, which addresses the areas of concern previously identified in the workshop steps (Brouwer *et al.*, 2012). The Action Plan is subject to review by a Peer Review Committee, composed of locally appointed farmers, after which the participant can access the cost-sharing aspect of the Environmental Farm Plan (Brouwer *et al.*, 2012). The Canada-Ontario Environmental Farm Plan is administered by the Ontario Soil and Crop Improvement Association

The cost-sharing opportunities available to participants of the Canada-Ontario Environmental Farm Plan are linked to the adoption of new beneficial, sometimes best, management practices (BMP) used to address the areas of concern identified in the Action Plan developed under the Environmental Farm Plan (Ontario Soil and Crop Improvement Association, 2009). The BMPs are divided into 28 categories, which are further divided into specific practices (practice code). Three BMP categories contain specific practices relevant to decreasing nutrient loadings in the Great Lakes region: manure treatment, nutrient recovery from waste water and resource planning. The BMP category resource planning includes nutrient management planning as a specific practice, enabling farmers to share the cost of voluntarily developing a nutrient management plan and the associated decision support tools (Ontario Soil and Crop Improvement Association, 2009).

2.5.7. Regulatory Policy

The Ontario Nutrient Management Act (2002) is an example of regulatory policy that specifically targets the agricultural sector, aiming to reduce the contamination of surface and ground water with nutrients, including manure and commercial fertilizer, from agricultural activities. The Nutrient Management Act (NMA) sets standards for nutrient application to agricultural land, the storage of nutrients, and construction requirements for new farm structures, aimed at reducing the risk of water contamination.

The Ontario Ministry of Agriculture and Rural Affairs (OMAFRA) and the Ontario Ministry of Environment and Climate Change (MOECC) share joint responsibility for the Nutrient Management Act (2002). The Nutrient Management Unit within OMAFRA is responsible for approval of Nutrient Management Strategies (NMS), Nutrient Management Plans (NMP) and Non-Agricultural Source Material Plans (NASM plans). The purpose of a NMS is to outline the environmentally acceptable method for managing all nutrient containing materials produced within an agricultural operation (OMAFRA, 2012). The purpose of a NMP is to outline nutrient application requirements within a given area (field and farm scale) (OMAFRA, 2012). The purpose of a NASM plan is to outline the application and storage requirements of nutrient containing Category 2 and 3 NASM within a NASM area (OMAFRA, 2012). OMAFRA outlines the specific technical and scientific standards under the NMA in the Nutrient Management Protocol (2012) to assist compliance with regulatory requirements (OMAFRA, 2012). All three plans and strategies can be completed through OMAFRA’s AgriSuite software program, or through workbooks developed by OMAFRA.

NMPs, created using the AgriSuite software program, automatically create nutrient balance sheets that contain the recommended NMAN rate for the specified field. The NMAN rate is based on the agronomic estimation of crop nutrient removal, aiming to balance nutrient flows in the field so nutrient inputs equal nutrient removal. This NMAN rate is only mandatory for farms that meet the regulatory requirements under the NMA, a description of the farms required the meet the NMA is outlined in Section 4.4. of this thesis. However, farms may voluntarily choose to adopt NMS or NMP as BMPs and may receive support, in the form of cost-sharing, from the Canada-Ontario Environmental Farm Plan. Farms required to meet the regulatory standards outlined in the NMA must do so without compromising their obligation to meet regulatory standards outlined in other relevant laws, including the *Environmental Protection Act*, Technical Standards and Safety Authority and the standards outlined in the Ontario Building Code (OMAFRA, 2012).

2.6. Summary

Identifying the sources of specific nutrient loadings in the Great Lakes region is difficult due to the diffuse nature of nutrient use in Ontario and the uncertainty associated with nutrient transportation mechanisms to surface water. Nutrients in agriculture are required to meet yield production goals, specifically in field crop production, but have been identified as a diffuse source of nutrient loadings within the Great Lakes region. As such, Government of Ontario has committed to reducing nutrient loadings outlined as goals in several international join agreements made across concerned parties including the Canadian federal government, the United States federal government and several State governments. To meet these goals, the Government of Ontario has several policy programs targeting reductions in excess nutrient use in agriculture, including the Canada-Ontario Environmental Farm Plan and the Nutrient Management Act.

3. Chapter 3: An Empirical Economic Analysis of of Farmer Nutrient Application Decisions in the Gully Creek Watershed

This chapter presents an empirical economic analysis in the Gully Creek watershed, assessing nutrient application decisions of nitrogen and phosphorus in corn and winter wheat production from 2008 to 2013. From this analysis I can understand what factors influence farmers' nutrient application decisions at a watershed scale.

I describe the Gully Creek watershed and the data used in the empirical analysis of farmer nutrient application behaviour. I statistically compare the actual nutrient application rate to a set of alternative rates, the recommended NMAN rate, the yield maximizing rate and the gross margin rate. I then examine if risk can explain farmer nutrient application behaviour by calculating the expected gross margin maximizing, for a risk neutral decision maker, and certainty-equivalents (CE), for a risk averse decision maker. I then develop a model based on farm physical characteristic to explain nutrient application decisions in excess of the recommended NMAN rate. I report the findings and discuss the implications of the results. The Tables for the chapter are contained in Section 3.7. and appear in order of discussion.

3.1. Introduction

The impact of excess application of agricultural nutrients on water quality in the Great Lakes region has become an area of concern for both the Canadian Federal, Ontario provincial, American Federal and State Governments (Dupont, 2010). The Great Lakes region has been subjected to various forms of environmental regulation and incentive programs focusing water quality since the harmful algae blooms in the late 1960s and early 1970s. Lake Erie has been the subject of scientific study focusing on understanding the root causes harmful algae blooms. Water enters the Western Basin of Lake Erie through the Detroit River, which flows from Lake

St. Clair which is in turn fed by Lake Huron. Regulations and incentives appeared to be addressing the issue of pollution in the Great Lakes region until the algae blooms began to reappear in the mid 2000s, renewing concern regarding nutrient loadings from agriculture (International Joint Commission, 2014). These previous policy efforts focused on identifiable point sources of nutrient pollutants, specifically municipal sewage treatment and industrial sources (International Joint Commission, 2014). Most recently Ontario, Ohio and Michigan signed the Western Basin of Lake Erie Collaborative Agreement pledging to reduce phosphorus entering the Lake Erie's western basin by 40% in the next 10 years (by 2025/2026) (Government of Ontario, 2015).

Agriculture has been identified by the International Joint Commission as a major source nutrient loadings in the Great Lakes region, estimated to account for 44% of total phosphorus loadings in Lake Erie (International Joint Commission, 2014). Agricultural nutrients, especially macronutrients nitrogen and phosphorus, are essential for plant growth, and are not necessarily available in sufficient concentration in the soil to promote optimal agricultural crop growth (Barker & Pilbeam, 2006; Blanco & Lal, 2008). Commercial field crop farming requires the application of fertilizers to maintain soil health and provide adequate nutrients for profitable crop production (Karlen *et al.*, 2004). In the Great Lakes region dissolved reactive phosphorus is the growth limiting nutrient in the case of algal blooms, as nitrogen has been found to be consistently available in sufficient concentrations in the water body (International Joint Commission, 2014). This study will focus on farmer's nutrient application decisions of both nitrogen and phosphorus to understand how famers are making decisions regarding nutrient application rates.

Agricultural nutrient use, and subsequently loadings into water bodies, is regulated in Ontario through the Nutrient Management Act (NMA) of 2002. The NMA is jointly managed by the Ontario Ministry of the Environment and Climate Change and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). This Act outlines nutrient management standards across producers of nutrients, including agriculture, municipalities and industry. Under the NMA, OMAFRA released the Nutrient Management Software Program (NMAN), updated to Ontario's Agriculture Planning Tool Suite (AgriSuite). NMAN was developed to assist farmers in managing nutrients at the farm and field scale, specifically targeting the nutrient capacity of soils (OMAFRA, 2015; Walters *et al*. 2013). The NMAN software uses a mass balance system[1] to account for nutrient inputs (such as manure and fertilizers) and nutrient losses (such as plant uptake, runoff and infiltration) (OMAFRA, 2015; Walters *et al*. 2013). NMAN is only a requirement for livestock operations with 300 or more Nutrient Units[2] (NU), expanding or new livestock facilities, or farms located within 100 metres of a municipal well. NMAN is currently voluntary for farmers who do not meet the aforementioned criteria (Walters *et al*., 2013).

Previous research indicates that farmers use numerous sources of information to inform fertilizer application decisions (Stuart, Schewe & McDermott, 2014). In Ontario, OMAFRA provides extension services, including publications and software support, to assist farmer in making farm management decisions. Farmers primarily rely on fertilizer dealers, seed company

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[1] A mass balance system calculates flows of nutrients into the system (inputs such as chemical fertilizer and manure) and flows of nutrients out of the system (crop removal). If crop removal equals nutrient inputs, this results in a net balance of 0.

[2] One nutrient unit is defined as the number of livestock that produce manure, a fertilizer replacement value, of either 43 kg of nitrogen or 55 kg of phosphate, which ever one is lower, on an annual basis. For example, a dairy herd of 70 cows, including heifers and calves, produces 127 NU per year. For multiple livestock types on a farm, multiple calculations of NU are required. The factors required for these calculations are available from OMAFRA and are an average of the nutrient content of the manure

agronomists as well as personal experience to make fertilizer application decisions (Stuart, Schewe & McDermott, 2014; Osmond *et al.*, 2015). Information and recommendations originating from university scientists and government extension agents was found to be distrusted by farmers (Stuart, Schewe & McDermott, 2014; Osmond *et al.*, 2015). The factors influencing farmer fertilizer application decisions are complex and merit further investigation.

The purpose of this paper is to compare farmers' actual application rates of nitrogen and phosphorus to the recommended NMAN rates and also to other agronomic and economic application rates. Data were obtained from a farm survey conducted in the Gully Creek watershed in 2011. The survey asked farmers to report actual crop yields and nutrient application rates from 2008 to 2010 and also asked them to project crop yields and nutrient application rates for 2011 to 2013. The total land area of the watershed is 1430 ha, of which agriculture is the primary land use on 994 ha. Surveys were completed by 16 farmers, who farmed 643.5 ha in the watershed.

The objective of the NMAN rate is to limit the application of nutrients to the rate of crop removal. If a farmer's actual application rates of fertilizer are greater than the recommended NMAN rates, this could contribute to excess nutrient loadings in surface water. Departure from the recommended NMAN rate could be attributed to alternative decision making criteria, such as gross margin maximization, yield maximization or risk aversion. Understanding why farmers apply more than the recommended NMAN rates can allow for modifications to the NMA that would lead to improved water quality. In contrast, if farmers' actual application rates of fertilizer are less than or equal to the recommended NMAN rates then further investigation as to the source of the increased nutrient loadings in the Great Lakes region is required to direct future water quality policy.

This paper begins with a case study site and data description, outlining the context of the analysis. The nutrient rate decision rules for fertilizer application rates are then discussed. A deterministic approach comparing alternative fertilizer application rates (NMAN rate, yield maximizing rate and gross margin maximizing rate) is used to examine farmers' decisions in the absence of risk. Yield response functional forms for corn and winter wheat are then described. The expected gross margin maximizing and certainty-equivalents (CE) for alternative rates are then calculated to incorporate risk for the risk neutral and risk-averse decisions maker. We use regression analysis to measure the effects of farm attributes on nutrient application decisions. Finally, we discuss the findings and the implications of this research.

3.2. Study Area and Data

Gully Creek is a 14.3 km^2 (1430 ha) sub-watershed of the Bayfield North watershed in Huron County that empties into Lake Huron. Lake Huron flows into Lake St. Clair which empties into the Western Basin of Lake Erie. Approximately 70% (994 ha) of the watershed's total area is allocated to agriculture with corn, soybeans and winter wheat the primary field crops (Oginskyy, 2014). In the Gully Creek watershed, the soils are largely clay loams, specifically Podsolic and Luvisolic (Oginskyy, 2014).

Under the OMAFRA watershed based BMP evaluation (WBBE) program, the Ausabule Bayfield Conservation Authority (ABCA) conducted a land management survey in March 2011. Farmers were asked to report historical land management practices were recorded for 2008, 2009 and 2010, and to project expected land management practices for 2011, 2012 and 2013 (Simmons *et al.,* 2013). The historical and projected survey data were verified with field observations from OMAFRA agricultural resource inventory (AgRI) (Simmons *et al.*, 2013). The projected survey data (2011-2013) were further verified by windshield surveys conducted by

ABCA, confirming that the projected crop type matched the actual crop in the field. The survey collected detailed observations of land management decisions on a field-by-field basis. Each field is assumed to receive uniform management practices and cropping decisions in a year. The details of the survey observations are outlined in Table 1. Of the farmers surveyed, none were required to meet the regulations outlined under the Nutrient Management Act, as the livestock operations were limited in size.

According to the survey data, the majority of farmers in the Gully Creek watershed follow a three-year corn-soybean-wheat rotation. This does not seem to vary with farm size, as is reported in Table 3. Corn is planted one year, followed by soybeans, which is then planted to winter wheat immediately after the fall harvest of soybeans. Across the survey sample, the total area under production each year on the surveyed farms is reported in Figure 4, organized by crop type: corn, winter wheat, soybeans and other. Where the other crop type includes crops such as edible beans, forages, barely, hay and land temporarily removed from production. In the projected observation period (2011-2013) the area under corn, winter wheat and soybeans equalizes in comparison to the historical observations.

Within the watershed, existing beneficial management practices (BMPs) used by farmers include conservation tillage, conservation buffers, water and erosion management, manure management and soil sampling. In corn production, conventional tillage is assumed to be the predominant practice, whereas for soybean and winter wheat production zero tillage is most commonly used. The choice of tillage practice depending on the crop grown known as rotational tillage is commonly used by crop farmers in southwestern Ontario.

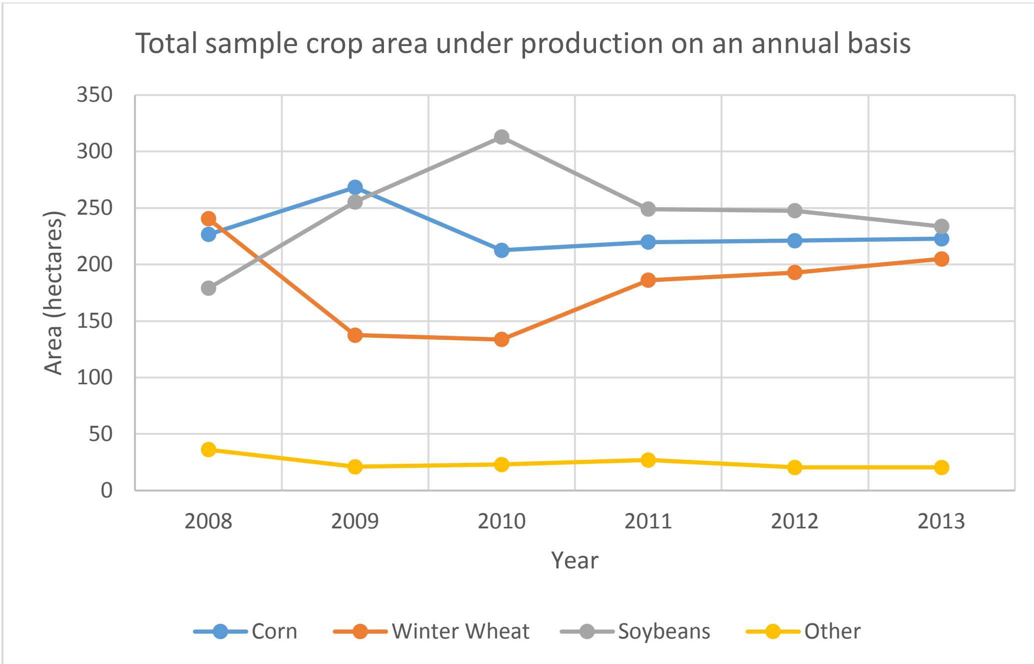

Figure 4: Total Sample Field Area Under Agricultural Crop Production

Some form of commercial chemical fertilizer was applied on all fields. Manure was applied to 57 of the 396 individual field observations across the six years of data (Table 3). Combining the chemical fertilizer application rate and the estimated available nutrients from manure, the actual fertilizer application rate was calculated on an individual field and annual basis. The assumptions for the available nutrient content of the manure are limited to poultry manure and is reported in Table 4. This actual rate serves as the basis to determine how the rates derived from alternative decision models compare to the actual.

3.3. Methods

3.3.1. Nutrient Rate Decision Rules

The fertilizer application rate used by a farmer can be guided by several criteria, including consideration of excess loadings and gross margin. Each of these will be compared to the actual application rate (N_A). The N_A is based on historical rates reported in a survey of farmers over time discussed in section 3. The actual rate will be compared to rates derived under three deterministic decision rules: (1) the voluntary adoption of the NMA rate (NMAN rate), (2) maximizing yield and (3) maximizing gross margin. The effects of nutrients as a risk increasing or risk decreasing input will also be considered. The basis for the decision rules behind these rates is discussed below.

3.3.1.1 NMAN Rate (N_E)

The rate that considers the environmental implications of fertilizer application is denoted as N_E. In Ontario, N_E is assumed to be the recommended NMAN rate as it aims to decrease excess nutrient application, which is calculated using the AgriSuite software package, designed and maintained by Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA). Field specific management plans from AgriSuite produce recommended rates for nitrogen and phosphorus fertilizer required to attain a specified yield. Factors such as soil type, soil fertility tests, crops planted in the previous year including the use of a cover crop and tillage practices are considered in the NMAN calculation. The NMAN rate minimizes excess application levels such that the nutrient requirement required to attain the stated yield are met but not exceeded. NMAN rate can be viewed as the environmental level or rate (N_E) as it theoretically minimizes excess application of nutrients, decreasing the risk of nutrient flows off farm and into the surrounding aquatic environment. If the actual application rate (N_A) is greater than the environmental rate (N_E), the excess application of fertilizer may lead to nutrients entering the surrounding environment.

3.3.1.2 Yield Maximizing Rate (N_{ya})

The yield maximizing rate (N_{Ymax}) is defined as the nutrient application rate that allows the crop to reach its maximal physical output per hectare in that cropping year. Determining the fertilizer rate that maximizes yield involves first specifying how application rates (*N*) influence crop yield (*Y*). Given a general yield response function

$$Y = f(N) \quad [1]$$

N_{Ymax} can be found by taking the first derivative of the yield response function given by [1], setting it equal to zero and solving for N,

$$N_{Ymax} \quad \text{where} \quad \frac{\eth f(N_{Ymax})}{\eth N} = 0 \quad [2]$$

This yield maximizing rate will differ for nitrogen and phosphorus and is dependent on empirically determined yield response function specific to nutrient and crop type.

3.3.1.3 Gross Margin Maximizing Rate ($N\pi$)

Assuming the farmer is risk neutral, the gross margin per land unit (π) is given by

$$\pi = P_y * Y - P_N * N \quad [3]$$

$$s.t.\ N > 0\ and\ Y = f(N) \quad [4]$$

where P_y is the crop price per unit of *Y*, P_N is the unit price of fertilizer and *N* is the nutrient application rate. The application rate that maximizes gross margin with respect to a single nutrient, gross margin *(*$N\pi$*)* is found by substituting the yield response function [4] into the gross margin [3], taking the derivative of the gross margin function with respect to the quantity of nutrient *N*, setting this first order condition to zero and solve for the corresponding *N* (Boyer *et al.* 2013; Nicholson, 2005):

$$N_{\pi} \quad \text{where} \quad P_y * \frac{\partial f(N_{\pi max})}{\partial N} = P_N \quad [5]$$

Maximization of the gross margin rate occurs when the value of an additional unit of fertilizer (left hand side of [5]) is equal to the incremental cost of the fertilizer or P_N (Rajsic *et al.*, 2009).

3.3.1.4 Expected Gross Margin Maximizing Rate ($N_{E\pi}$)

The gross margin maximizing rate derived in the previous sub-section assumed deterministic conditions with no risk on prices, yields or nutrient amounts. Assuming yield is subject to a random shock θ with a mean of μ_θ and a variance of σ_θ^2, expected gross margin ($E(\pi)$), can be expressed as

$$E(\pi) = \int \pi * s(\pi) d\pi$$

where $\pi = P_y * f(N_A, \theta) - P_N * N$ and $Y = f(N_A, \theta)$; $\theta \sim (\mu_\theta, \sigma_\theta^2)$ [6]

where $s(\pi)$ is the probability density function of gross margin (π). The risk risk-neutral decision maker will select the nutrient application rate ($N_{E\pi}$) that maximizes expected gross margin.

3.3.1.5 Expected Utility Maximizing Rate (N_{EU})

In the case of a risk averse farmer, the farmer will choose to maximize expected utility of the gross margin ($EU\ (\pi)$) rather than maximize the expected gross margin. This is true if we assume that nutrients are a risk increasing input (Rajsic *et al.*, 2009). The associated maximization problem can be expressed as

$$\max_N EU(\pi) = \int U(\pi) * s(\pi) d\pi \qquad [7]$$

where $U(\pi)$ is the utility function of gross margin and $s(\pi)$ is the probability density function of gross margin (Rajsic *et at.* 2009). Robinson and Barry (1987) demonstrate the maximizing the expected utility of gross margin is equal to the certainty equivalent of gross margin ($CE\pi_{kA}$), assuming a constant absolute risk-aversion utility function and normally distributed gross margins. $CE\pi_{kA}$ is given by

$$CE\pi_{kA} = E\pi_A - \frac{\lambda_k}{2} \sigma_{\pi A}^2 \qquad [8]$$

where $E\pi_A$ is the expected gross margin specified in [8], π_A is the gross margin from applying rate N_A , λ_k is the coefficient of absolute risk-aversion for farmer *k* and $\sigma^2_{\pi A}$ is the variance of gross margin for rate N_A ($\sigma^2_{\pi A} = E[\pi_{tA} - E\pi_A]^2$) where π_{tA} is the year specific gross margin from applying N_A. If the variance of yields, and thus gross margin, increases with the application rate, then fertilizer is a risk increasing input. Thus, even though higher nutrient application rates increase average yield, a risk averse farmer may apply less than the gross margin maximizing rate if fertilizer is a risk increasing input (Rajsic *et al.*, 2009).

To calculate the variance of the certainty equivalent of gross margin ($CE\pi_{kA}$) we calculated the population variance for the three deterministic fertilizer application scenarios (N_N, N_{Ymax} and $N\pi$), as well as the actual nutrient application rate for a baseline comparison. After calculating the certainty equivalent of gross margin ($CE\pi_{kA}$) for each farmer in each of the four scenarios we found the population mean ($\mu = \sum(CE\pi_{kA_i})/n$) for the four scenarios. Where $CE\pi_{kA_i}$ is the certainty equivalent of gross margin for each year and *n* is the total number of observations and the four scenarios are the actual application rate, the NMAN rate, the yield maximizing rate and the gross margin maximizing rate for nitrogen. We used the population mean to find the population variance (σ^2). Population variance is given by

$$\sigma^2 = \frac{\sum(CE\pi_{kA_i} - \mu)^2}{n} \qquad [9]$$

where $CE\pi_{kA_i}$is the certainty equivalent of gross margin for each year, μ is the population mean and *n* is the total number of observations.

3.3.2. Calculation of Alternative Application Rates

The actual application rate (N_A) is the rate reported by farmers in the survey described in Section 3.2. The recommended NMAN rate by Kevin McKague at OMAFRA, based on data obtained from the survey. The observations on field fertility and desired yield were as inputs into AgriSuite that generated the N_E.

The actual rate will also be compared to the rates suggested by alternative decision rules in addition to the NMAN rate that is calculated for the farmers. These decision rules all involve specifying a crop specific yield response function to fertilizer ($Y=f(N)$). The yield response functions were adapted from existing empirical agronomic studies, Rajsic and Weersink (2008) and OMAFRA (2015) conducted in Southwestern Ontario in regions with similar climactic and soil characteristics. A quadratic functional form was used for both corn and winter wheat. The corn yield response function to nitrogen was adapted from empirical research conducted in South Western Ontario from 1990 to 1992 (Rajsic and Weersink, 2008). The corn yield response function is

$$Y_C = 1431 + 48.33*N - 0.1364*N^2 \quad [10]$$

where Y_C is the corn yield, measured in kg/ha/yr, and N is the nitrogen application rate measured in kg/ha/yr.

The winter wheat yield response function to nitrogen was adapted from an empirical study conducted in South Western Ontario from 2003 to 2005 (OMAFRA, 2015). The winter wheat yield response function is

$$Y_W = 54.99 + 0.5963*N - 0.0019*N^2 \quad [11]$$

where Y_W is the wheat yield, measured in bu/ac, and N is the nitrogen application rate, measured in lb/ac. These values were converted into metric for comparison in the results section.

Soybeans typically do not require the application of nitrogen fertilizer to meet yield expectations due to the nitrogen fixation properties of the crop.

Yield response functions for phosphorus were unavailable for the crops and within the region of the case study. As such, we were unable to calculate the yield maximizing and gross margin rate for phosphorus fertilizer in winter wheat, corn and soybeans. We therefore compared the actual application rate for phosphorus to the NMAN rate for phosphorus.

3.3.3. Empirical Comparison

We conducted a comparison of the actual nutrient application rate (N_A) to the rates associated with the alternative decision rules. It is assumed among the three decision rules without risk that

$$N_Y > N_\pi > N_E \qquad [12]$$

The yield maximizing rate (N_Y) will be greater than the gross margin maximizing rate (N_π) by definition unless fertilizer price is zero, in which case the decision rules will result in the same rate. We also assumed that the NMAN rate is less than the gross margin maximizing rate since the former limits nutrient loadings caused by over-application, whereas the later rate does not.

The actual rate for nitrogen and phosphorus will be compared for each crop to each of three alternative rates, using a paired t-test. Our first hypothesis is that the actual rate is greater than the NMAN rate

$$N_A > N_E \qquad [13]$$

If this is the case, then excess nutrient application may be occurring, if the NMAN rate is valid. On the other hand, levels below the NMAN rate ($N_A < N_E$) would suggest that, at least in the local study area farmers are not applying excess nutrients.

If the first hypothesis given by [13] does hold, the second focus is to determine the reasons for the actual application rates. If there is no statistically significant difference between the actual rate and the gross margin maximizing rate but both are above the NMAN rate,

$$N_A = N_\pi > N_E \quad [14]$$

then financial incentives would be required to reduce the rate to incentivize farmers to apply nutrients at the NMAN rate. On the other hand, educational efforts would be required to inform farmers of the financial and environmental implications of applying at a rate equal to the yield maximizing rate, as the application of nutrients at the yield maximizing rate decreases farm profits and may increase the cost of environmental damage off farm,

$$N_A = N_Y > N_\pi > N_E \quad [15]$$

3.3.3.1. Empirical Comparison in the Case of Production Risk

In case of production risk analysis for risk-neutral farmers, a comparison between the expected gross margin of the actual application rate and the expected gross margins of the three alternative application rates was conducted. To compare the expected gross margin of the actual application rate, which is considered the base rate, we took the difference between the actual application rate and the alternative rates, at both the individual farmer scale and average for the specific crop and nutrient. The risk-neutral farmer would be expected to choose the nutrient application rate with the greatest expected gross margin. Comparing these results to the deterministic scenarios all us to understand how risk influences farmers' nutrient application decision-making.

In the case of production risk analysis for risk-averse farmers, to compare the actual application rate to the three alternative applications rates, we found the variance of the certainty equivalents as described in equation [9]. The risk-averse farmer would be expected to choose the nutrient application scenario that minimizes that variance. While we are not in a position to characterize the risk preferences of farmers in the watershed empirically, by using representative levels of risk aversion taken from the literature, we are able to examine the potential effects of risk aversion on differences between actual application rate, the NMAN rate and the alternative rates (yield maximizing and gross margin maximizing).

We used regression analysis to examine the influence of farm characteristics on farmers' decisions to apply fertilizer in excess of crop requirements. We used ordinary least squares (OLS) regression regressing the difference between the actual nutrient application rate and the recommend NMAN rate in corn and winter wheat production for each field farm physical characteristics described in Table 2. The regression equation is expressed as

$$(N_A - N_E) = \beta_0 X_1 + \beta_1 X_2 + \cdots + \beta_6 X_7 + \beta_7 + \varepsilon \qquad [16]$$

where $N_A - N_E$ is the difference between the actual application rate and the recommended NMAN rate,

β_i are the regression coefficients,

X_i are explanatory variables, including farm size in hectare, field size, also in hectares, crop rotation, a dummy variable, yield in metric tons per hectare, manure applied, a dummy variable, an economic variable for each nutrient capturing the relationship between nutrient price and crop price in each year (P_N/P_Y) and the complimentary nutrient application rate in kg/ha/yr in the current growing season,

and ε is the error term. The explanatory variables specified in the regression are outlined and described in Table 2. We had no prior expectations on the signs of the coefficients on farm size, field size, crop rotation and last year's crop. We hypothesized that yield is linked to an increase between the actual application rate and the recommended NMAN rate, as farmers have been found to apply fertilizer in excess of crop requirements (Sheriff, 2005). The explanatory variable for the difference of the actual application rate and the NMAN rate for the complimentary nutrient is hypothesized to have a positive effect on the dependent variable as the decision to over apply one nutrient may lead to excess application of the complimentary nutrient.

3.4. Results

3.4.1. Actual Application Rates (N_A)

To find average annual actual nutrient application rates per hectare for the three primary agricultural crops: corn, winter wheat and soybeans, we calculated the area weighted average of the rates applied to all fields in production of the specified crop in a cropping year. The area weighted average (defined as $\sum rate * field\ area / \sum field\ area$) allows us to look at the specified nutrient application decision across fields and weigh the nutrient application rates as a function of area. Table 5 reports the range of nutrient application rates the number of fields in production of the specified crop in each year.

Before proceeding with further analysis on the actual application rates, we examined the validity of including the predicted nutrient application rates (2011 to 2013 observations) in the empirical analysis. To do this we compared the observed rates for 2008 to 2010 to the predicted application rates for 2011 to 2013 through visual inspection and statistical tests. In Figure 5, the 2012 predicted nitrogen application rates for corn, on an individual field scale, are all less than 200 kg/ha/yr and the average actual application rate of nitrogen in corn was at its lowest in the six years of observations. In contrast, the predicted nitrogen application rates in corn production for 2013 include the second highest rate, 227 kg/ha/yr across the six-year period of observations. The 2012 average actual application rate of nitrogen in winter wheat is the second highest across the six years of observations (Table 5). The predicted average application rates reported in 2012 and 2013 vary across crops (Table 5). These variations in the average actual application rates and the individual field nutrient application rates observed in 2012 and 2013 suggest that farmers are likely reporting realistic land management plans for the 2011-2013 period.

To verify further the farmer survey responses, we divided the data set into the two periods of observations, and compared the variance and the means of the two periods to confirm that the predicted data was valid for further analysis. We found no statistical difference between the historical observations (2008-2010) and the predicted observations (2011-2013), in either the mean or variance, for the actual application rates of nitrogen and phosphorus. Therefore, based on the facts discussed above the predicted observations (2011 to 2013) will be treated in the same way as the historical actually data (2008 to 2010).

Comparing corn and winter wheat production, the yield responses to both nitrogen and phosphorus, given the range of nutrient application rates, are flat and clustered in the Gully Creek watershed across the six years of observations. Corn yield response to nitrogen across the nutrient application rate (112 kg/ha/yr – 309 kg/ha/yr) was between 9 metric tons/ha and 12.9 metric tons/ha. Phosphorus application in corn production occurred primarily between 18 kg/ha/yr and 58 kg/ha/yr, with a yield response between 9 metric tons/ha and 12.9 metric tons/ha. The winter wheat yield response function to nitrogen across the majority of the nitrogen application rate (100 kg/ha/yr – 150 kg/ha/yr) was between 4.8 metric tons/ha and 7 metric tons/ha. The Phosphorus application rate in winter wheat production ranged between 0 kg/ha/yr and 38 kg/ha/yr with a yield response between 4.8 metric tons/ha and 7 metric tons/ha. Construction of yield response functions from the actual nutrient application rate data collected in the survey was not possible due to the flat yield responses and narrow nutrient application ranges.

Comparing across crops, the average actual application rate of nitrogen across years' fits expected agronomic trends. For example, the average actual application of nitrogen in 2009 for corn is 188.6 kg/ha/yr, which is greater than the average rate for winter wheat (116.7 kg/ha/yr) and soybeans (3.0 kg/ha/yr). The lower average actual nitrogen application rates in soybean production are expected as soybeans fix nitrogen from the atmosphere, typically providing the crop nitrogen requirements for production. Both the highest maximum actual application rate of nitrogen in soybean production (67 kg/ha/yr) and the highest average actual application rate of nitrogen (8.4 kg/ha/yr) occurred in 2008. The cause of this spike in nitrogen application rates in soybean production is unknown. The range of values for the actual application rate of nitrogen follows a similar pattern as the average with a few notable exceptions. In corn production in 2009, both the maximum and minimum actual application rates of nitrogen are greater than any other year. The maximum actual application rate in 2009 is 308 kg/ha/yr, 81 kg/ha/yr greater than any other year and the minimum actual application rate in 2009 is 150 kg/ha/yr, 27 kg/ha/yr greater than any other year. However, the average actual application rate in 2009 of corn is only marginally greater than the other years of observations.

The average actual application rate of phosphorus across crops also follows expected agronomic trends across the six years of observations. For example, in 2011, the average actual application rate of phosphorus in corn production (14.7 kg/ha/yr) is greater the average actual rate of phosphorus in winter wheat (9.5 kg/ha/yr) and soybeans (2.6 kg/ha/yr) production. The range of values of the actual application rate of phosphorus varies more than for nitrogen across crops and years. A notable exception is the difference between the maximum and the average actual application rate of phosphorus in corn production. In the case of nitrogen, the maximum actual application rate in four of the six years is less than 30% higher than the average actual application rate, for example in 2008 the maximum and average actual application rate were 209 kg/ha/yr and 188.5 kg/ha/yr respectively. In the case of phosphorus, the average rate is much smaller than the maximum rate, differing between 75% and 270% across the six years of data, indicating that in more of the fields farmers choose to apply less fertilizer, decreasing the simple average in that year

3.4.2. NMAN Application Rates (N_E)

The field management plans from AgriSuite produce the NMAN recommended rates for nitrogen and phosphorus fertilizer required to attain a specified yield. The AgriSuite software operates as a simple input/output program, the farmer enters the required input parameters and field history, reported in Table 6, and calculations are performed by program resulting in the output tables, reported in Table 7. Constructing the yield response functions to nitrogen and phosphorus used by the AgriSuite software package was not possible as the NMAN rates mirrored the same flat responses observed Figure 5 for the actual data.

The AgriSuite output includes a field management plan that contains the recommended NMAN rate. Table 7 presents an example of the field management plan directly from AgriSuite for a field selected randomly from the data set. In the case of winter wheat, given the crop requirements, there is a deficit of nutrients applied to the field given crop requirements in the 2008 production year. However, the AgriSuite program only accounts for soil nutrients given the input of a soil nutrient test or the historical record of field activities (previous crops, yields, and nutrient application rates). In the case of corn production in the 2009 cropping year, at the specified yield of 11.6 metric ton/ha, given the excess nutrients available in the field, the recommended NMAN rate was 171 kg/ha/yr for nitrogen and 60 kg/ha/yr for phosphorus. The tables produced by AgriSuite are used a guide and require interpretation on the part of the farmer to understand if the field contains excess nutrient balance or is becoming depleted (McKague, 2016). Meaning that the AgriSuite output does clearly state the recommended NMAN rate

Table 8 presents the area weighted averages of the NMAN rate (nitrogen and phosphorus) for corn, winter wheat and soybeans on an annual basis for the six years of survey data. The area weighted average (defined as $\sum rate * field\ area / \sum field\ area$) allows us to look at the specified nutrient application decision across fields and weigh the nutrient application rates as a function of area. The recommended NMAN rates for nitrogen fit the expected agronomic values across crops, where the nutrient recommendations for corn are greater than the nutrient recommendations for winter wheat, which are greater than the nutrient recommendations for soybeans. In 2010 the average NMAN application rate for nitrogen is 180.7 kg/ha/yr in corn production, 96.1 kg/ha/yr in winter wheat production and 0 kg/ha/yr in soybean production. An exception to the general agronomic trends is the maximum NMAN application rate for nitrogen in soybean production in 2008, 2012 and 2013, as soybeans typically fixate nitrogen sufficiently for crop requirements. In 2008, the average NMAN application rate in winter wheat is 20% greater than any other years' average NMAN application rate. The higher average rate in 2008 could be partially explained by the minimum NMAN application rate, which is, at 111 kg/ha/yr, is 12% higher than the of 2012, the next highest year.

In the case of phosphorus, the average NMAN application rates also fit the expected agronomic values across crops, where in 2010 the average NMAN application rate for phosphorus is 24.2 kg/ha/yr in corn, 1.1 kg/ha/yr in winter wheat and 0 kg/ha/yr in soybean production. The maximum NMAN application rate for phosphorus in soybean production in 2010 (0 kg/ha/yr) is an exception to the other years of observations. This could be explained by the AgriSuite program identifying excess phosphorus from the the previous years cropping years being available in the field at the soybean crop requirements.

3.4.3. Comparison of Actual Nutrient Application Rates to NMAN Recommendations

Comparing the average annual nutrient application rates at the watershed scale for nitrogen in corn production, the average actual nitrogen application rate is equal to or less than the average NMAN nitrogen application rate, reported in Tables 8. The average annual actual phosphorus application rates in corn are, across all years, greater than the average NMAN phosphorus application rate. In 2008, the average actual phosphorus application rate was 47.2 kg/ha/yr in corn production, 70% greater than the 2008 average NMAN phosphorus application rate of 27.7 kg/ha/yr. The difference between the actual phosphorus application rate and the NMAN phosphorus application rate in corn production can also be observed by comparing the maximum application rates in Table 5 and 8. The maximum actual phosphorus application rates in 2008, 2009 and 2011 are between 54% and 129% greater than the maximum NMAN phosphorus application rate.

A deterministic application rate comparison for corn is reported in Table 9. A comparison of the average actual nutrient application rate for nitrogen to the average recommended NMAN rate and the gross margin maximizing rate indicates that there is no statistical difference across the three rates. The average NMAN rate is 1.36 kg/ha/yr more than the average actual application, and the gross margin maximizing rate is 3.78 kg/ha/yr less than the average actual application rate. However, examining the comparison between the actual application rate and the NMAN rate for each individual farmer demonstrates a high level of data heterogeneity. In the case of nitrogen in corn production, five farmers are applying in excess of the NMAN rate by up to 37.94 kg/ha/yr and eight farmers are applying up to 53.92 kg/ha/yr below the recommended NMAN rate. Of the 16 farmers surveyed only three are applying at the recommended NMAN rate for nitrogen in corn production. In the case of phosphorus in corn production all 16 farmers are apply at or above the recommended NMAN rate. Of the 16 farmers, nine are applying phosphorus up to 36 kg/ha/yr above the recommended NMAN rate of 9 kg/ha/yr.

In the case of winter wheat, we found that the average actual application rate of nitrogen was not statistically similar to the NMAN rate, the yield maximizing rate or the gross margin maximizing rate, reported on Table 10. Focusing on the individual farmers, four are applying in excess of the recommended NMAN rate, three are applying below the recommended NMAN rate and six are applying at a rate equal to the recommended NMAN rate. In the case of phosphorus in winter wheat production, only one farmer was on average applying in excess of the NMAN rate. This farmer grew winter wheat in 2010, 2012 and 2013 and accounted for 13.51 ha, 52.58 ha and 13.51 ha of area under winter wheat production in the respective years. When we removed this farmers' nutrient application observations from the data set the average actual application rate for phosphorus is statistically similar to the recommended NMAN rate. Meaning that a single farmer is responsible for the application of phosphorus in excess of the NMAN rate in the case of winter wheat production.

3.4.3.1. Production Risk and Risk-neutral Farmers

The expected gross margin values, measured in dollars, for the alternative nitrogen application rates, are subtracted from the expected gross margin values for the actual application rate for each of the 16 farmers as well as average of the data set, reported in Table 11. In the case of corn, the gross margin maximizing rate ($E\pi_{\pi max}$) is the optimal choice for a risk-neutral decision maker. This is consistent with the results for the deterministic rate comparison above in

Table 9, where the average gross margin maximizing rate was not statistically significantly different from the actual application rate. The average of the NMAN expected gross margin ($E\pi_{NMAN}$) is similar the average of the gross margin maximizing expected gross margin. This lends validity to the legitimacy and strength of the NMAN rate in regards to farmers' economic performance.

3.4.3.2. Production Risk and Risk-averse Farmers

Table 12 reports variance of the certainty equivalent gross margin for the actual nitrogen application rate and the three alternative nitrogen application scenarios (NMAN rate, yield maximizing rate, and the gross margin maximizing rate), for corn and winter wheat, given λ_k equal to 0.001. We chose the absolute risk-aversion coefficient (λ_k) equal to 0.001 as it represents a strong risk aversion (Raskin & Cochran, 1986). Of the possible nutrient application rates the optimal nutrient rate would be N_{Ymax} as it has the lowest variance, reported in Table 10, for both corn and winter wheat production. In the deterministic rate comparison, N_{Ymax} was not statistically similar to the actual nutrient application rate for either corn or winter wheat, see Tables 9 and 10. Within the Gully Creek watershed, based on the available data, the certainty equivalent analysis indicates that farmers risk aversion fails to explain actual nutrient application decisions.

3.4.4. Empirical Comparison

Table 13 reports the estimated regression coefficients for equation [15] for the dependent variable is the actual application rate less the recommended NMAN rate at the field scale. Where every individual nutrient application decision, every field in every year, is considered as a separate observation. We ran four separate model scenarios, the cases of nitrogen and phosphorus for both corn and winter wheat. The coefficients for farm size are significant and positive across all of the four models, indicating that larger farms are more likely to apply nutrients at a rate greater than the recommended NMAN rate. This could be linked to dependence on farm income in the larger farms, where farmers are concerned with providing sufficient nutrients to attain the maximum yield of the crops. The coefficients for manure, which represents if the farm used manure as a nutrient source, in corn production, are large and positive in the case of nitrogen and negative in the case of phosphorus. This indicates that farmers who apply manure in corn production, are likely to apply excess nitrogen and insufficient phosphorus given the crop requirements specified by the NMAN calculation. The opposite is true in winter wheat production for nitrogen, the coefficient for manure is significant, large and negative. This indicates that in fields with winter wheat production, the application of manure is linked to a decreased nitrogen application rate below crop requirements.

The coefficient for yield is significant, large and negative for nitrogen in both corn and winter wheat production and significant and small for phosphorus in winter wheat production. The large and negative in coefficient for nitrogen in both corn and winter wheat indicates that the greater the yield, the less likely the case of excess fertilizer application. In the case of the phosphorus model for winter wheat the coefficient for yield is positive, indicating that as the yield increase, the likelihood of over the actual application rate exceeding the recommended NMAN rate increases.

3.4.5. Nutrient Loadings at Across the Gully Creek Watershed

At the watershed scale, the corn production accounts for the greatest share of both nitrogen and phosphorus loading. The nutrient load is defined as the quantity, in this case the weight (kg) entering an area, the watershed, in a given period of time, on an annual basis. The total load of nutrients applied is reported in Table 14 for corn production and Table 15 for winter wheat production. Where the gross load is the total weight of nutrients applied in the watershed and the net load is the total load less the crop requirements as defined under the NMAN rate. Corn accounts for majority of the nutrient load in the watershed, accounting for 65.50% of the nitrogen load and 80.28% of the phosphorus load. Across the six years of observations, the net nitrogen load, in corn and winter wheat, is only 5.2%% greater than the gross load. Meaning that in the case of nitrogen, the actual load of nitrogen was only 5.24% greater than the recommended NMAN load. However, it is important to note the actual mass of this excess load associated with the high gross load of nitrogen. In the watershed, the excess load of nitrogen, across the six years of data, was equal to 20,458.34 kg, of which, corn production accounts for 46.34%. This demonstrates that while corn production accounts for a greater share of the gross nitrogen load, winter wheat accounts for a greater share of the net nitrogen load. This supports the findings discussed in Section 3.4.3., where the actual application rate of nitrogen is statistically similar to the NMAN rate in the case of corn production by not winter wheat production.

In the case of phosphorus loading, the net load is of concern as it accounts for 47.28% (31,266.06 kg) of the gross load. Corn accounts for the majority of gross phosphorus loadings (80.28%), and as corn as a crop requires more nutrients than winter wheat, as observed in Tables 5 and 8, the greater share of the net phosphorus load fits agronomic expectations. The net phosphorus loading in both corn and winter wheat production are high, 37.83% and 85.77% of the gross phosphorus load respectively. This supports the findings in Section 3.4.3. where the actual application rate was not statistically similar to the recommended NMAN rate for both corn and winter wheat. Corn accounts for 64.23% (20,083.01 kg) of the net phosphorus load, where as winter wheat accounts for 35.77% (11,183 kg) of the net phosphorus load. As phosphorus has been identified as the growth limiting factor for harmful algae blooms in Lake Erie, the high level of the net phosphorus load at the watershed scale should concern the Government of Ontario, specifically OMAFRA and MOECC.

3.4.6. Outliers

The majority of outliers contained within the data set are linked to a single farmer, and are occur in the case of phosphorus application. This farmer applied manure, followed the three crop rotation (corn - winter wheat – soybeans) and had a total farm area of approximately 200 ha. Removing these outliers did not influence the results for nitrogen or phosphorus in case of corn production, and nitrogen in the case of winter wheat production. In the case of phosphorus in winter wheat production, discussed in Section 3.4.3., when we removed the single farmer responsible for the outliers, the actual application rate was statistically similar to the recommended NMAN rate. This is important to note as it demonstrates that a single individual can be responsible for the application of nutrients in excess of the recommended rate within a watershed. However, we included the observations associated with this farmer as the empirical analysis focused on examining farmers' nutrient application decisions at the watershed scale.

3.5. Conclusions

The purpose of this paper was to compare farmers' actual nutrient application rate decisions to the NMAN standard and to a set of agronomic and economic decision rules in order to explain application rates that appear to be excessive to plant nutrient requirements. Deviations of actual application rates from NMAN recommended rates were regressed on farm characteristics to identify factors linked to an increased likelihood of excess fertilizer application decisions.

The data indicate that farmers' decisions to apply in excess of the recommended NMAN rate are linked to crop and nutrient type. We only found evidence of excess nutrient application occurs only for nitrogen in corn The analysis of individual fertilizer application decisions, where each field in each year of production is treated as an observation, found that farm size was both positively and significantly linked to excess fertilizer application across both corn and winter wheat in cases of both nitrogen and phosphorus, meaning that larger farms are more likely to apply nutrients in excess of the recommended NMAN rate. The analysis of individual fertilizer application decisions also found that the specified crop yield was significantly and negatively linked to excess fertilizer application for nitrogen in both corn and winter wheat production and phosphorus in corn production. This indicates that fields with lower yielding corn and winter wheat were more likely to have excess nitrogen application, and in lower yielding corn production, excess phosphorus application.

The application of manure in corn production, as a nutrient source for nitrogen, was found to have a positive and significant influence on the application of excess nitrogen. The opposite is true for manure application in winter wheat production, where when manure is present in winter wheat production, there is a decrease in the nitrogen application rate below the NMAN rate. In the case of phosphorus application, the application of manure in corn production was found to have a negative and significant link, meaning that phosphorus was applied at a rate less than the NMAN rate. Where as in winter wheat, there was no significant relationship for the manure coefficient in the case of phosphorus application decisions.

Within the Gully Creek watershed, none of the 16 farms in the data set were regulated under the Nutrient Management Act (NMA). Meaning no farms were required to use Nutrient Management Plans, and the NMAN rate when applying manure. The result of the excess nitrogen application associated with the use of manure in crop production merits further investigation to see if regulation should be extended to farmers using manure, but not required to meet the regulations of the NMA. Additionally, the net nutrient loadings at the watershed scale, specifically for phosphorus, indicate that nutrient applications in excess of the NMAN rate are occurring. Nutrient applications in excess of crop requirements, when analyzed at the scale the rate per hectare, can fail to communicate the seriousness of the issue of excess nutrient applications. Expanding the analysis to examine nutrient loadings at a watershed scale is important as it demonstrates small contributions can multiply over a large area.

3.6. Chapter 3. Tables

Table 1: Details of Land Management Survey Observations (Oginskyy, 2014)

Observation Category	Details
Field physical characteristics	Physical boundaries and location, slope and soil type recorded in GIS shape file
Crop	Crop type, seeding date and seeding rate
Tillage	Tillage type (ex. conventional: moldboard or chisel) and date
Fertilizer management	Application rate, date and method (ex. side applied, broadcast or banded)
Manure management	Application rate, type, available nutrients and date
Yield	Historical and predicted[3]
BMPs[4]	Existing BMPs used by farmers
Soil Survey	Soil nutrient levels of phosphorus, potassium, pH and organic matter

[3] where historic yields are for both the NMAN and the actual application rate for the time period 2008-2010 and the predicted yields are for both the NMAN and actual application rate for the time period 2011-2013

[4] Beneficial management practices (BMPs) including conservation tillage, soil testing schedules, shelter belts, fragile land retirement, buffer strips, and berms

Table 2: Explanatory Variables for the OLS Regression for the Dependent Variable ($N_A - N_E$)

		Corn			Winter Wheat		
Dependent Variable	Description	Mean	Minimum	Maximum	Mean	Minimum	Maximum
$N_A - N_E$ (N)	The difference between the actual nutrient application rate and the NMAN rate, for nitrogen (N) and phosphorus (P)[5]	-1.36 kg/ha/yr	164.00 kg/ha/yr	-93.00 kg/ha/yr	7.89 kg/ha/yr	57.00 kg/ha/yr	-105.00 kg/ha/yr
$N_A - N_E$ (P)		13.50 kg/ha/yr	76.00 kg/ha/yr	-1.00 kg/ha/yr	7.47 kg/ha/yr	39.00 kg/ha/yr	-9.00 kg/ha/yr
Explanatory Variable	**Description**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Farm size	Overall size of farm within the watershed (ha)	110.02 ha	334.88 ha	11.06 ha	132.79 ha	334.88 ha	19.85 ha
Field size	Total field size (ha)	10.55 ha	93.44 ha	0.09 ha	13.50 ha	93.44 ha	0.44 ha
Crop rotation	Dummy variable for crop rotation on the field, 0 for a two crop rotation[6] and 1 for the three crop rotation[7]	-	-	-	-	-	-
Economic variable	The ratio of the price of the nutrient ($/metric ton) to the price of the crop ($/metric ton) — N[8]	290.89	206.87	379.48	254.62	202.81	375.82
	P	7.80	5.34	12.16	7.10	5.73	13.15
Yield	Specified for the field in the given crop year, either target or actual depending on the year (metric ton/ha/yr)	10.81 metric ton/ha/yr	12.80 metric ton/ha/yr	8.80 metric ton/ha/yr	5.84 metric ton/ha/yr	7.40 metric ton/ha/yr	4.20 metric ton/ha/yr
Manure	Dummy variable for crop (0) or livestock (1), where manure application is taken as a proxy for livestock operation	-	-	-	-	-	-

[5] Where the complimentary nutrient used as an explanatory variable is the phosphorus in the case of the dependent variable nitrogen and nitrogen in the case of the dependent variable phosphorus

[6] a combination of corn/winter wheat/soybeans

[7] a typical three crop rotation of corn-winter wheat-soybeans

[8] Where N represents nitrogen and P represents phosphorus

Table 3: Farm Descriptive Statistics

Farm	Number of Fields	Farm Area (ha)	Crop Rotation	Manure application[9]	BMP[10]
1	3	24.12	C/S/WW[11]	Yes	Yes
2	2	41.91	C/S/WW	Yes	Yes
3	1	11.46	C/S	No	Yes
4	5	85.45	C/S/WW	Yes	Yes
5	13	207.66	C/S/WW	Yes	Yes
6	3	11.92	C/S/WW	Yes	Yes
7	9	57.80	C/S/WW/O[12]	No	Yes
8	3	40.31	C/S/WW	Yes	Yes
9	1	19.85	C/S/WW	Yes	Yes
10	3	6.15	C/S/WW	Yes	Yes
11	2	17.41	C/S/WW	No	Yes
12	5	10.44	C/S/O	No	No
13	2	2.11	C/S/WW	No	No
14	2	31.11	C/S/WW	Yes	No
15	5	25.15	C/S/WW	Yes	Yes
16	7	28.83	O	No	No
Total	66	643.05			
Average	4.125	40.19			

[9] Where manure application indicates manure was applied to at least one of the fields within the farm across the period of observations

[10] Where BMP (Beneficial Management Practice) indicates the presence of some BMP on farm through the period of observations. The BMPs within the Gully Creek watershed include conservation tillage, soil testing schedules, shelter belts, fragile land retirement, buffer strips, and berms

[11] Where C/S/WW/O represent the crop rotation of corn, soybeans, winter wheat and other crops used by the farmer across the entire period of observations

[12] Where the other crop type includes crops such as edible beans, forages, barely, hay and land temporarily removed from production

Table 4: Assumptions of Available Nutrient Content of Poultry Manure

Manure type	Available Nutrient Content	
	Nitrogen (kg/ metric ton)	Phosphorus (kg/metric ton)
Poultry	7.1	6.3

Table 5: Actual Nutrient Application Rates of Nitrogen and Phosphorus, Annual Averages of 67 Fields, Minimum and Maximum Values for Corn, Winter Wheat and Soybeans

		Corn				Winter Wheat				Soybeans			
Fertilizer	Year[13]	*n*[14]	Avg	Min	Max	*n*	Avg	Min	Max	*n*	Avg	Min	Max
Nitrogen	2008	27	188.5[15]	122	209	10	129.3	112	160	21	8.4	0	67
	2009	15	188.6	150	308	12	116.7	112	133	32	3.0	0	12
	2010	20	182.7	112	227	15	109.8	0	171	22	2.0	0	10
	2011	17	182.1	112	209	16	0.8	31	135	25	1.6	0	6
	2012	23	173.5	112	209	15	123.9	112	135	21	3.2	0	40
	2013	23	178.3	123	227	11	121.2	73	146	25	0.5	0	22
Phosphorus	2008	27	47.2	14	135	10	2.4	0	27	21	7.5	0	40
	2009	15	39.8	14	91	12	2.3	0	15	32	4.9	0	20
	2010	20	35.1	0	54	15	11.2	0	39	22	3.9	0	40
	2011	17	14.7	0	135	16	9.5	0	32	25	2.6	0	13
	2012	23	26.1	0	54	15	10.9	0	39	21	5.0	0	24
	2013	23	33.8	0	54	11	14.1	0	39	25	0.7	0	13

[13] Where 2008-2010 are the historical observations and 2011-2013 are values survey respondents were asked to project. Projected values were cross checked, with windshield surveys conducted by the ABCA in subsequent years

[14] Number of fields in production of the specified crop in a given year

[15] Area weighted average of the actual application rate of on a field basis in the given year

Table 6: AgriSuite Input Parameter Requirements to Create a Field Management Plan

Category	Details
Location	Upper and lower tier municipality, geotownship and crop heat units
Field physical properties	Tillable area, area available for nutrient application, maximum slope, slope length, soil series, soil texture, hydrologic soil group and runoff potential
Soil test results	Sample date, soil test results: phosphorus (ppm), potassium (ppm), pH and organic matter (%)
Crop/cropping year	Crop type, expected yield, planting and harvest date, tillage method and timing, previous crop nitrogen credit, price of corn and cost of nitrogen
Fertilizer application	Fertilizer type and blend, application date, method and rate
Additional optional inputs	Grazing and non-agricultural source material

Table 7: AgriSuite Output for Recommended NMAN Rates in 2008 and 2009, Winter Wheat and Corn Production Respectively

	2008 Winter Wheat NMAN rate (kg/ha/yr) (yield 5.8 metric ton/ha)			2009 Corn NMAN rate (kg/ha/yr) (yield 11.6 metric ton/ha)		
Category	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Previous material credit[16]	15	0	0	6	0	0
Manure[17]	0	0	0	111	270	183
Broadcast fertilizer[18]	91	0	0	83	0	0
Crop nutrient requirements	-189	-68	-158	-171	-87	-60
Starter fertilizer[19]	0	0	0	0	0	0
Nutrient balance	-83[20]	-68	-158	29[21]	183	123

[16] The previous material credit incorporates the previous cropping years residual or excess nutrients into the current year’s calculation

[17] The AgriSuite software package contains assumptions for the nutrient content of manure with the available option for modification of those assumptions if the farmer conducts nutrient content tests

[18] Commercial fertilizer spread on the surface of the soil

[19] Fertilizer applied in close proximity to the seed at the time of seeding to provide a nutrient boost through the initial growth phase of the crop

[20] Insufficient nitrogen available for winter wheat given nutrient inputs and yield specified

[21] Excess nutrients applied given for corn given crop requirements at specified yield

Table 8: NMAN Nutrient Application Rates of Nitrogen and Phosphorus, Annual Averages of 67 Fields, Minimum and Maximum Values for Corn, Winter Wheat and Soybeans

Fertilizer	Year[22]	Corn				Winter Wheat				Soybeans			
		n[23]	Avg	Min	Max	*n*	Avg	Min	Max	*n*	Avg	Min	Max
Nitrogen	2008	27	185.6[24]	122	220	10	128.9	111	136	21	6.3	0	36
	2009	15	171.4	122	208	12	98.2	76	116	32	0.0	0	0
	2010	20	180.7	142	215	15	96.1	89	144	22	0.0	0	0
	2011	17	164.1	122	206	16	107.5	91	125	25	0.0	0	0
	2012	23	174.5	122	205	15	104.9	99	122	21	0.7	0	24
	2013	23	179.4	122	204	11	121.2	88	136	25	0.0	0	22
Phosphorus	2008	27	27.7	0	59	10	0.4	0	26	21	3.1	0	17
	2009	15	26.8	9	59	12	1.0	0	9	32	0.3	0	13
	2010	20	24.2	0	54	15	1.1	0	29	22	0.0	0	0
	2011	17	22.2	0	59	16	1.4	0	20	25	0.8	0	13
	2012	23	17.5	0	54	15	1.0	0	20	21	0.6	0	13
	2013	23	22.1	0	54	11	0.0	0	11	25	0.0	0	11

[1]The number of fields under production in the given year

[2]Simple un-weighted average of the actual application rate of on a field basis in the given year

[22] Where 2008-2010 are the historical observations and 2011-2013 are the predicted observations verified by windshield surveys conducted by the ABCA

[23] Number of fields in production of the specified crop in a given year

[24] Area weighted average of the actual application rate of on a field basis in the given year

Table 9: Comparisons of Area Weighted Average Farm Level Actual Nutrient Application Rates with NMAN and Other Application Rates (kg/ha/yr) for Corn Production in the Gully Creek Watershed from 2008-2013

	Nitrogen				Phosphorus	
Farm	N_A	N_A - N_E	N_A - $N_{\pi max}$	N_A - N_{ymax}	N_A	N_A - N_E
1	207.07[25]	37.94[26] (0.000)[27]	42.20 (0.000)	29.38 (0.166)	54	0 (0.500)
2	196.09	0.74 (0.249)	32.95 (0.288)	18.40 (0.484)	37.40	0.00 (0.196)
3	150.00	0.00 (0.211)	-14.52 (0.010)	-27.79 (0.000)	45.00	36.00 (0.000)
4	205.83	12.93 (0.024)	41.00 (0.000)	28.15 (0.000)	36.55	0.00 (0.173)
5	191.43	30.65 (0.000)	26.82 (0.000)	13.75 (0.002)	53.01	34.80 (0.000)
6	190.27	30.70 (0.001)	25.93 (0.000)	12.58 (0.000)	21.41	0 (0.178)
7	167.92	-26.70 (0.000)	3.49 (0.017)	-9.76 (0.036)	20.36	-11.42 (0.000)
8	150.00	-53.92 (0.000)	-12.77 (0.000)	-27.71 (0.000)	33.00	0.21 (0.000)
9	179.00	-27.50 (0.017)	14.36 (0.077)	1.16 (0.043)	30.59	0.00 (0.250)
10	183.01	-23.60 (0.000)	19.76 (0.001)	5.32 (0.014)	19	-5.26 (0.187)
11	157.00	-42.68 (0.003)	-8.88 (0.007)	-20.71 (0.000)	23.54	14.46 (0.001)
12	94.28	-31.62 (0.000)	-32.19 (0.000)	94.28 (0.000)	22.23	15.33 (0.000)
13	144.00	-58.00 (0.000)	-22.32 (0.000)	-33.73 (0.000)	22.00	13.00 (0.000)
14	63.43	-47.95 (0.007)	-100.64 (0.000)	-114.25 (0.000)	-[28]	-
15	179.37	12.21 (0.190)	14.73 (0.465)	1.68 (0.260)	50.01	21.77 (0.030)
16	164.00	35.47 (0.000)	-0.58 (0.287)	-13.70 (0.000)	14.00	5.00 (0.000)
Average	168.26	-1.36 (0.349)	3.78 (0.150)	-9.42 (0.005)	32.19	13.50 (0.000)

[25] The area weighted average of the farmers' actual application rate (kg/ha/yr) across the six years of observations
[26] The difference between the actual application rate and the recommended NMAN rate, averaged across all fields in corn production (kg/ha/yr)
[27] p-value for the t-test, comparing all individual observations for the individual famer
[28] Observation unavailable due to insufficient data

Table 10: Comparisons of Area Weighted Average Farm Level Actual Nutrient Application Rates with NMAN and Other Application Rates (kg/ha/yr) for Winter Wheat Production in the Gully Creek Watershed from 2008-2013

Farm	Nitrogen				Phosphorus	
	N_A	N_A - N_E	N_A - $N_{\pi max}$	N_A - N_{ymax}	N_A	N_A - N_E
1	112.00[29]	17.00[30] (0.124)[31]	11.53 (0.013)	-60.64 (0.000)	0	0 -
2	136.23	7.66 (0.108)	85.68 (0.039)	-36.40 (0.071)	13.17	0.00 (0.196)
3	-[32]	-	-	-	-	-
4	109.20	17.23 (0.001)	35.08 (0.003)	-63.44 (0.000)	0.00	0.00 -
5	129.02	16.32 (0.000)	54.83 (0.000)	-43.62 (0.000)	29.10	29.10 (0.000)
6	86.51	10.50 (0.093)	7.99 (0.270)	-86.13 (0.060)	0.00	0 -
7	112.00	9.76 (0.004)	38.25 (0.007)	-60.64 (0.000)	0.00	-0.64 (0.041)
8	112.00	-10.33 (0.000)	56.47 (0.016)	-60.64 (0.000)	0.00	0.00 -
9	74.67	11.33 (0.092)	4.02 (0.324)	-97.97 (0.060)	0.00	0.00 -
10	110.40	2.63 (0.300)	43.06 (0.383)	-62.24 (0.036)	11.00	-0.68 (0.196)
11	113.13	10.72 (0.091)	22.96 (0.079)	-59.50 (0.000)	0	-7.79 (0.091)
12	-	-	-	-	-	-
13	112.00	11.00 (0.000)	15.57 (0.010)	-60.64 (0.000)	0.00	0.00 -
14	80.59	-29.82 (0.023)	-11.12 (0.168)	-92.05 (0.000)	6.00	0.40 (0.173)
15	50.06	-11.14 (0.009)	-22.29 (0.001)	-122.58 (0.0001)	0.00	0.00 -
16	-	-	-	-	-	-
Average	107.59	7.89 (0.027)	26.20 (0.000)	-65.05 (0.000)	9.92	7.47 (0.000)

[29] The area weighted average of the farmers' actual application rate (kg/ha/yr) across the six years of observations
[30] The difference between the actual application rate and the recommended NMAN rate, averaged across all fields in corn production (kg/ha/yr)
[31] *p*-value for the t-test, comparing all individual observations for the individual famer
[32] Observation unavailable due to insufficient data

Table 11: Comparison of the Difference in Expected Gross Margin for the Actual Nitrogen Application and Expected Gross Margin from NMAN Rate, and the Alternative Rates (Gross Margin Maximizing Rate and Yield Maximizing Rate) for Corn and Winter Wheat

	Corn			Winter Wheat		
Farmer	$E\pi_A$ - $E\pi_E$	$E\pi_A$ - $E\pi_{\pi max}$	$E\pi_A$ - $E\pi_{Ymax}$	$E\pi_A$ - $E\pi_E$	$E\pi_A$ - $E\pi_{\pi max}$	$E\pi_A$ - $E\pi_{Ymax}$
1	-40.01[33]	-41.96	-37.41	50.08	32.26	-55.81
2	-13.60	-34.76	-29.62	0.15	139.85	-11.25
3	0.00	-6.42	-1.92	-[34]	-	-
4	-24.21	-54.80	-50.25	33.64	84.91	-32.32
5	-36.86	-43.10	-38.55	55.00	116.12	-7.96
6	-11.68	-16.93	-12.26	203.25	192.92	41.75
7	24.30	-3.50	1.05	25.40	95.14	-36.10
8	36.07	-5.28	-0.19	-17.96	137.77	-42.81
9	44.08	-5.87	-0.91	42.65	28.05	-47.40
10	39.26	-9.11	-4.16	27.99	155.33	-25.26
11	24.05	-1.93	2.52	17.30	114.62	-33.77
12	-51.08	-52.79	-48.58	-	-	-
13	19.86	-13.66	-10.25	24.57	31.88	-38.13
14	-69.89	-95.04	-91.69	-135.04	-97.34	-170.65
15	-5.97	-10.73	-5.86	-60.85	-88.89	-164.34
16	35.95	-0.27	4.30	-	-	-
Average	-0.83	-3.90	0.65	18.58	87.74	-36.33

Table 12: Variance of Certainty Equivalent Gross Margin for Alternative Nitrogen Nutrient Application Rates, with λk = 0.001

	Corn	Winter Wheat
N_A	3,845[35]	19,185
N_{NMAN}	5,345	20,581
$N_{\pi max}$	5,267	25,458
N_{Ymax}	5,251	19,259

[33] The expected gross margin across the six years of observations for the actual application of nitrogen less the expect gross margin for the recommended NMAN the crop specified, if positive than $E\pi_A > E\pi_i$

[34] Observation unavailable due to insufficient data

[35] The variance of the certainty equivalent, calculated using the population mean and variance across the period of observations, risk averse decisions makers would choose the application rate with the lowest variance

Table 13: Explaining Differences between Actual and NMAN Nutrient Application Rates in Terms of Farm Characteristics for Corn and Winter Wheat Production for the Dependent Variable (N_A - N_E)

	Corn		Winter Wheat	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Farm Size	0.236[36]***[37]	0.107***	0.183***	0.124***
	(0.039)[38]	(0.015)	(0.064)	(0.007)
Field Size	-0.017	-0.136	-0.036	-0.137**
	(0.258)	(0.110)	(0.195)	(0.054)
Crop Rotation	-30.700***	-2.660	-12.919	-0.942
	(7.884)	(4.537)	(8.457)	(1.707)
Economic Variable (N[39])	-2.144	0.001	0.087	-0.007
	(1.071)	(0.014)	(0.053)	(0.007)
Economic Variable (P[40])	0.055	0.766*	-2.744**	-0.010
	(0.037)	(0.394)	(1.270)	(0.246)
Yield[41]	-15.643***	-0.186	-12.093**	2.290**
	(2.203)	(0.988)	(5.372)	(0.961)
Manure[42]	22.087***	-6.848*	-28.308**	-1.265
	(7.437)	(3.228)	(11.297)	(3.032)
Phosphorus Difference	-0.196	-	-0.583	-
	(0.229)		(0.380)	
Nitrogen Difference	-	-0.009	-	-0.006
		(0.035)		(0.011)
Constant	160.645***	2.963	71.114**	-17.151***
	(26.562)	(11.564)	(32.158)	(6.575)
Number of observations	131	131	85	85
R-squared	0.62	0.57	0.50	0.90
Adjusted R-squared	0.60	0.55	0.45	0.89

[36] Regression coefficient
[37] *p*-value less than 0.01 is denoted by ***, 0.05 ** and 0.10 *
[38] The standard deviations are in parenthesis
[39] N is for nitrogen
[40] P is for phosphorus
[41] Both actual (as specified for the actual application rate of nutrients) and target (as specified for the AgriSuite calculation of AgriSuite)
[42] Dummy variable for manure application, where 0 is no manure, and 1 is the application of manure

Table 14: Total and Excess Nutrient Loadings for Corn Production in the Gully Creek Watershed on an Annual Basis, and Total Across the Six Years of Observations						
Year	Gross Nitrogen Load (Kg)[43]	Net Nitrogen Load (Kg)[44]	Percentage of Excess to Total[45]	Gross Phosphorus Load (Kg)	Net Phosphorus Load (Kg)	Percentage of Excess to Total
2008	45,391.79	697.35	1.54%	11,354.67	4,681.69	41.23%
2009	50,617.51	4,625.97	9.14%	10,673.25	3,469.23	32.50%
2010	38,845.66	426.30	1.10%	7,458.10	2,305.37	30.91%
2011	42,198.48	4,187.40	9.92%	10,245.41	5,100.19	49.78%
2012	38,800.25	-227.53	-0.59%	5,830.54	1,922.61	32.97%
2013	39,740.68	-228.56	-0.58%	7,526.98	26,03.92	34.59%
Total[46]	255,594.36	9,480.93	3.71%	53,088.94	20,083.01	37.83%
Corn and Winter Wheat Total[47]	390,216.70	20,458.34	5.24%	66,127.87	31,266.06	47.28%

[43] The total nutrient load, measured in kilograms, applied in the watershed

[44] The gross nutrient load, measured in kilograms, less the crop requirements, as defined by the NMAN rate, which is the excess nutrient load within the watershed

[45] The $\frac{\text{net nutrient load}}{\text{gross nutrient load}} * 100$

[46] The total nutrient load across the six years of observations for corn production

[47] The total nutrient load across the six years of observations for both corn and winter wheat production

Table 15: Total and Excess Nutrient Loadings for Winter Wheat Production in the Gully Creek Watershed on an Annual Basis, and Total Across the Six Years of Observations						
Year	Gross Nitrogen Load (Kg)[48]	Net Nitrogen Load (Kg)[49]	Percentage of Excess to Total[50]	Gross Phosphorus Load (Kg)	Net Phosphorus Load (Kg)	Percentage of Excess to Total
2008	31,105.62	97.23	0.31%	3,672.87	2,585.54	70.40%
2009	16,054.85	2,555.72	15.92%	314.38	178.85	56.89%
2010	15,967.15	1,992.71	12.48%	2,095.55	1,931.22	92.16%
2011	21,329.62	1,048.21	4.91%	1,792.52	1,522.90	84.96%
2012	23,882.43	3,650.48	15.29%	2,109.20	1,915.10	90.80%
2013	26,282.67	1,633.08	6.21%	3,054.42	3,049.45	99.84%
Total[51]	13,4622.34	10,977.41	8.15%	13,038.93	11,183.05	85.77%
Corn and Winter Wheat Total[52]	390,216.70	20,458.34	5.24%	66,127.87	31,266.06	47.28%

[48] The total nutrient load, measured in kilograms, applied in the watershed

[49] The gross nutrient load, measured in kilograms, less the crop requirements, as defined by the NMAN rate, which is the excess nutrient load within the watershed

[50] The $\frac{\text{net nutrient load}}{\text{gross nutrient load}} * 100$

[51] The total nutrient load across the six years of observations for corn production

[52] The total nutrient load across the six years of observations for both corn and winter wheat production

4. Chapter 4: Evaluation of the Nutrient Management Act

The previous chapters of this thesis have focused on the history of the regulatory framework surrounding nutrient management in Ontario and an empirical analysis of farmer nutrient application decision making in the Great Lakes region. The results in Chapter 3 found that on average farmers voluntarily tend to apply nutrients at the recommended NMAN rate, as outlined by the Nutrient Management Act, for nitrogen but not phosphorus. The purpose of this chapter is to examine how the Nutrient Management Act (2002) is used by the Government of Ontario to regulate nutrient management in Ontario agriculture. This chapter begins by explaining Nutrient Management Act, the tools used in its enforcement and the farms required to meet the regulatory standards outlined the Act. The chapter closes by examining the enforcement of the Nutrient Management Act as reported through the Ontario Court Bulletin.

4.1. The Nutrient Management Act (2002)

The Ontario Nutrient Management Act (2002) specifically targets the agricultural sector, aiming to reduce the contamination of surface and ground-water with nutrient containing materials, including manure and commercial fertilizer, from agricultural activities. The Nutrient Management Act (NMA) outlines standards for nutrient application to agricultural land as well as the storage of nutrients, to reduce the risk of environmental contamination. Within the NMA a framework of best management practices for nutrient management, specifically for manure, is outlined.

The Ontario Ministry of Agriculture and Rural Affairs (OMAFRA) and the Ministry of Environment and Climate Change (MOECC) share joint responsibility for the Nutrient Management Act (2002) (NMA). The Nutrient Management Unit within OMAFRA is responsible for approval and design of Nutrient Management Strategies (NMS), Nutrient Management Plans (NMPs) and Non-Agricultural Source Material Plans (NASM Plans), to assist farmer compliance with the NMA. The MOECC is responsible for enforcement and compliance of the NMA. Agricultural Environmental Officers (AEO), from MOECC, are provincial officers trained agriculture who conduct surveys and when required, use compliance tools to ensure farmers adherence to regulation under the NMA (OMAFRA, 2016c).

4.2. The Theory of the Probability of Detection and Fines in Environmental Regulation

The issue of farms regulated under the NMA choice to comply or violate the NMA is a problem of asymmetrical information. Assuming farms decision to comply or violate the NMA is a discrete choice, farms know if they are in compliance or violation the NMA, where the MOECC does not. If a farm chooses to comply with the NMA they have the certainty of no penalty but there is no opportunity for potential farm gains. Violation of the NMA may result in decreased BMP costs, environmental damage on or off the farm, and the risk of detection which may result in a penalty. For the risk-neutral farmer, the optimal decision to violate the NMA can be modeled as:

$$b \geq Pf \qquad [17]$$

where b is the benefit of violating the the NMA, P is the probability of detection and f is the penalty or fine if the violation is detected. If the benefits associated with violating the NMA are greater than the potential penalty, the rational farmer would choose to violate the NMA. For the risk-averse farmer, the optimal decision to violate the NMA can be modeled as:

$$b + a \geq Pf \qquad [18]$$

where b is the benefit of violating the the NMA, a is the risk premium (where $a>0$), P is the probability of detection and f is the penalty or fine if the violation is detected.

To increase farmer compliance with the NMA, the MOECC can either decrease the cost of compliance, through cost sharing programs, making it easier to comply, or increase the size of Pf. The MOECC can increase the size of Pf by either increasing the size of fines with a small probability of detection, or increase the probability of detection with a smaller size of fines. Increasing the probability of detection, the enforcement of the NMA by AEOs by the MOECC, increases the fixed enforcement cost to the Ministry (Polinsky & Shavell, 1992). The fixed enforcement cost for the MOECC can be assumed to be the continued cost of sustaining the probability of detection at a specified level (Polinsky & Shavell, 1992). Increasing the size of the fine increases the variable enforcement costs as it is cost associated with the fine is dependent on the number of individuals in violation, this variable enforcement costs includes the cost of penalizing and prosecuting individuals (Polinsky & Shavell, 1992). To find the optimal probability of detection and optimal fines a social welfare model discussed by Polinsky and Shavell was adapted for the farm and is briefly discussed below.

For the risk-neutral farm, the decision to violate the NMA, described in equation [17], is assumed to be discrete. Social welfare is the benefits to society less the costs to society. In the case of enforcement of the NMA the benefits to society are the sum of benefits of the individual farms, the costs to society are the costs of the environmental harm caused by the violation of the NMA and the fixed and variable costs of enforcement of the NMA. The social welfare can be expressed as:

$$\int_0^\infty \int_{Pf}^\infty (b - h - Pk) r(b) \partial b g(h) \partial h - c \qquad [19]$$

where

$$b \geq 0$$

$$r(b) \geq 0 \; when \; b \geq 0$$

$$h \geq 0$$

$$g(h) \geq 0 \ when \ h \geq 0$$

$$P(0) = 0, P'(c) > 0 \ and \ P"(c) < 0$$

where *b* is the benefit to the farm, *h* is the cost of the harm caused by the violation, *P* is the probability of detection of a violation, *k* is the variable cost of imposing the fine, *r(b)* is the is the probability density of *b* over individuals, *g(h)* is the probability density of *h* over individuals and *c* is the fixed enforcement cost (Polinsky & Shavell, 1992). This method requires the MOECC to find an environmental damage function, and assume that the harm associated with the violation of the NMA is constant. Maximizing social welfare, the solution to the social problem involves the choice *c*, directly linked to the probability of detection, and a set of *f* to maximize equation [19] (Polinsky & Shavell, 1992).

Increasing the right hand side of equation [17] involves a trade off between increasing the probability of detection or increasing the schedule of fines. The optimal level of fines and optimal probability of detection vary in respect to one another (Polinsky & Shavell, 1992). Increasing the fines is the most cost efficient method for decreasing violations, however constraints including wealth and political reasons limit the socially acceptable size of the fines (Cohen, 1998; Polinsky & Shavell, 1979). In Ontario and Canada, specific policy effort has focused on farm income support, this political effort to support farms may indicate a lack of political will to increase fines that target farm violators of the NMA. Increasing the probability of detection with respect to the NMA has a high cost due to the difficulty of detection of nutrient sources. The research conducted in Chapter 3 relied on voluntary self reporting of nutrient application rates based on a good-will relationship between the farmers in a small watershed and the local Conservation Authority. Collecting similar information from farms regulated under the

NMA is not likely possible for reasons including confidentiality. Intensive academic research by both Canadian and American research institutions have yet to specifically identify nutrient sources across the Great Lakes region (International Joint Commission 2014). It is reasonable to assume that identifying specific farms contribution nutrient loadings from diffuse sources will be challenging and thus costly.

The goal of the MOECC as an environmental agency can be assumed to be achieving the greatest level of compliance with the NMA given a set enforcement budget (Cohen, 1998; Garvie & Keeler, 1994). We can assume that MOECC will increase the size the *Pf* term in Equation [1] to deter farmers from violating the NMA. How the MOECC increases the size of the *Pf* term Equation [17] will depend on political priorities, budgetary constraints and staffing capability.

4.3. Compliance of the Nutrient Management Act

AEOs conduct inspections on farms that fall under the regulation of the NMA to assess compliance. AEOs can make both recommendations and outline requirements to the farmer to meet compliance under the NMA. Depending on the severity and nature of the non-compliance the AEO has five compliance tools that can be used to enforce compliance with the NMA. The five compliance tools available to the AEO, listed in increasing severity below:

1. Abatement program
2. Amend conditions of the Nutrient Management Strategy (NMS) or Nutrient Management Plan (NMP)
3. Issue of a Provincial Officer's Order
4. Issue a *Provincial Offences Act* Ticket
5. Referral to the Investigations and Enforcement Branch (IEB)

The abatement program involves the AEO making an oral or written request to individual responsible for the non-compliance to voluntarily adopt an abatement program within an agreed upon time period. These oral and written requests address minor issues with compliance typically due to lack of knowledge and with low risk of environmental consequences. Abatement programs include the measures required to meet compliance as well as the period in which the measures must be completed (OMAFRA, 2016c).

The AEO can request an amendment of the nutrient management strategy (NMS) or nutrient management plan (NMP) if the existing NMS/NMP does not accurately capture the on farm situation, or if AEO deems existing NMS/NMP to insufficiently protect the environment due to local conditions and factors. To amend an existing NMS/NMP the AEO requests the Approvals Unit at the Nutrient Management Unit within OMAFRA to amend an existing condition of approval for the existing NMS/NMP (OMAFRA, 2016c).

A Provincial Officer's Order is a legal document outlining specific requirements and actions for an individual or group of individuals to address an issue of non-compliance with the NMA. Provincial Officer's Orders are used by AEOs to address non-compliance issues that will likely prevent the discharge of nutrient containing materials into the environment. AEOs may also issue a Provincial Officer's Order if there is reasonable doubt that the individual will not voluntarily adopt an amended NMS/NMP or abatement program. Individuals have the option to request a review of the Provincial Officer's Order a Director at the local MOECC office and may be further appealed Environmental Review Tribunal within a predefined time period (OMAFRA, 2016c).

The issuing a *Provincial Offences Act* ticket by an AEO can occur when serious environmental consequences are likely to occur due to non-compliance, or when an individual is unwilling to obey an existing Provincial Officer's Order or abatement program issued by the AEO. *Provincial Offences Act* tickets are issued with a preset fine that falls under the jurisdiction of the Provincial Offences Court. The individual named on the ticket may plead guilty and pay the fine, resulting in a conviction, plead guilty with an acceptable reason or plead not-guilty and defend themselves in court (OMAFRA, 2016c).

The referral by the AEO to the Investigations and Enforcement Branch (IEB) of the MOECC occurs only in the most sever cases on non-compliance, where further investigation and possible prosecution may be warranted. Sever cases of non-compliance include the obstruction of Ministry personnel and negligence leading to environmental consequence. If the investigation conducted by the IEB results in prosecution, the individual is subject to a Part III summons under the *Provincial Offences Act* (OMAFRA, 2016c).

To guide the AEO in the selection of compliance tools for a given violation of the NMA, three levels, in escalating in severity, are outlined in Table 16. The selection of the level of compliance tools is based on the individuals' compliance history, intent, the environmental consequences of the violation and the individual circumstances of the issue (OMAFRA, 2016c).

An example of a level one non-compliance: a farmer has established vegetated buffer strips along a creek in compliance with a NMP or NMS, but AEO found the vegetated buffer strips, in few areas, not compliant with the required width under the NMA. As the farmer has no previous compliance violation and the changes required to meet compliance are minimal, the AEO may issue a written request to the farmer to voluntarily adopt an abatement program increasing the width of the vegetated buffer strip to meet the compliance level in a predetermined period (OMAFRA, 2016c).

An example of a level two non-compliance: the farmer discussed in the level on example has failed to increase the width of the vegetated buffer strips voluntarily within the predetermined period. As this is an ongoing violation of the NMA the AEO could issue a Provincial Officer's Order requiring the farmer to increase the width of the vegetated buffer strips (OMAFRA, 2016c).

An example of a level three non-compliance: while conducting a survey of a property with a reported manure spill, the AEO is refused access to the reportedly affected area by the land owner. The land owner is obstructing the AEO and denying property access. The AEO would report the obstruction to the IEB for further investigation and could result in prosecution of the land owner (OMAFRA, 2016c).

4.4. Farms Requirements of the Nutrient Management Act

Not all farms in Ontario are required to create NMS, NMP or NASM plans under the NMA. The NMA requires the creation and approval of a NMS for the farms meeting one or more of the following conditions:

- Construction of new livestock housing or manure storage facility, including manure storage facilities made of earth (lagoons)
- Increasing nutrient units produced on farm to greater than 300 with existing livestock housing facilities
- Farming operations within 100 m of a municipal well
- Farms receiving nutrient containing materials from a regulated off-farm mixed anaerobic digester
- Change in farm ownership or control with an existing NMS, where the change could be deemed to affect the ability of the new individual operator to implement existing NMS

Farms required to have an approved NMP must first be required to have a NMS. Farms with existing NMS are required to create a NMP if the farm is a livestock operation with a nutrient unit load of 300 or more, and/or the land in agricultural production is located within 100 m of a municipal well. The NMP process can be beneficial for farmers to voluntarily create a NMP as it can increase fertilizer use efficiency, decrease fertilizer purchase costs and decrease the risk of environmental contamination with agricultural nutrients.

Farms that receive category two and three non-agricultural source materials (NASM), including bio-solids from sewage, pulp and paper production, and materials residual materials from food processing require NASM plans. Category one NASM, which includes un-composted yard waste, does not require a NASM plan so long as the material application rate is not in excess of 20 metric ton/ha on a wet weigh basis. Category two NASM include materials containing metals such as wash water from a brewery or organic waste. Category three NASM include wash water from a diary processing facility and sewage bio-solids.

In Ontario, 6,172 farms, totaling 708,906 ha of agricultural land, meet the conditions defined under the NMA requiring the creation and approval of a NMS or NASM plan Ontario, reported in Table 17 These regulated farms account for 11% of farms or 14% of total agricultural land in. The NMA, specifically NMS, focus on agricultural operations producing nutrient units, indicating the presence of livestock within the farming operation. Farms producing nutrient units and required to have a NMS account for 25% of livestock farms in Ontario.

4.5. Enforcement of the Nutrient Management Act

Information regarding the use of compliance tools for enforcement of the NMA is confidential. Publically available information is limited only to the most serious compliance tool, referral to

MOE's investigations and enforcement branch, which has resulted not only in an investigation but in a conviction and fine from an Ontario justice under the *Provincial Offenses Act*. These convictions and fines are reported in the Ontario court bulletins both current and archival (Ontario, 2016). The information regarding the archival court bulletins are limited, dating back only to the beginning of 2012. The details of these convictions and fines are outlined in Table 18.

Convictions and fines can be levied against the party deemed responsible for the violation of the NMA, either a farm owner or an associated or contracted company. These companies can include engineering firms responsible for the design and construction of manure management systems. Across the four years of available data, twelve convictions and fines were levied violations of the NMA, accounting for 0.2% of all farms regulated under the NMA. Of the convictions and fines across the four years of data, six (50%) were levied against non-farm businesses and six (50%) were levied against individual farm owners. However, it is important to not that the proportional dollar value of these fines is not equally divided between the responsible parties. Individual farms account for only $22,950 (9.6%) of the dollar value of the fines, where as non-farm businesses account for $215,000 (90.4%) of the dollar value of the fines. Meaning the average fine levied against a farm was $3,825 and the average fine levied against a company was $35,833, almost ten times the size of the average farm fine. From the size of the fines levied against companies it could be inferred that the violations that resulted in convictions were more serious in nature than the violations committed by individual farms.

4.6. Conclusions

Based on the available information, the small number and dollar value of the convictions and fines levied against farms, there are two possible cases for farmer compliance with the NMA. The first possible case is that famers required to meet the standards outlined in the NMA are complying to some acceptable level, where violations are effectively dealt with by the AEO and farmer using the first four compliance tools. Farmers regulated under the NMA are effectively modifying their nutrient management behaviour and should, on average, be minimizing the risk of ground and surface water contamination with agricultural nutrients. This supports the findings of the empirical research discussed in Chapter 3, where farmers, on average, are voluntarily applying nutrients at the recommended rate stemming from the NMA.

The second possible case is that farmer compliance and MOECCs enforcement of the NMA is not viewed as a priority. Service Ontario lists 13 AEOs across the province, of which two specialize in pollinator health, down from 16 in 2007 (Bradshaw, 2007; Service Ontario, 2016). Meaning that each AEO, including the two that specialize in pollinator health, is responsible for monitoring 475 farms for compliance with the NMA. The publically available information regarding enforcement of the NMA is lacking, but given the conviction rate of farmers for violations of the NMA, 0.1% of total farmers regulated, further data on the use of compliance tools is required to fully evaluate farmer compliance with the NMA. Further research is merited to understand if the NMA is effective at changing farmer nutrient management behaviour.

4.7. Chapter 4. Tables

Table 16: Levels of Compliance Tools, Selected Based on Compliance History and Intent of the Responsible Party, Available to AEO for Enforcement of the NMA (OMAFRA, 2016c)

Level	Compliance History and Intent	Compliance Tools
One	• No compliance history • Previous violation (unrelated) • Previous violation (related)	• Abatement program • Amend approval conditions of the nutrient management strategy or plan • Issue a Provincial Officer's Order • Issue a *Provincial Offences Act* ticket
Two	• On going violation	• Amend approval conditions of the nutrient management strategy or plan • Issue a Provincial Officer's Order • Issue a *Provincial Offences Act* ticket • Referral to MOE's investigations and enforcement branch
Three	• Previous significant convictions • Obstruction of AEO	• Amend approval conditions of the nutrient management strategy or plan • Issue a Provincial Officer's Order • Referral to MOE's investigations and enforcement branch

Table 17: Ontario Farms Regulated Under the NMA Compared to the Total Number of Livestock Farms in Ontario and the Total Number of Farms in Ontario, both as Number of Farms and the Area of Agricultural Land (OMAFRA, 2016; Wilson, 2015)

Farm Type	Number of farms	Total agricultural land (ha)
Nutrient Management Strategies for farms with 5 < NU < 300	3,453	361,401
Nutrient Management Strategies for farms with NU ≤ 300	1,263	253,696
Non-Agricultural Source Material plan	1,456	93,809
Total farms with NMS	4,716	615,097
Total farms regulated by the NMA	6,172	708,906
Total livestock farms in Ontario (2011)[53]	19,207	-
Total Ontario farms (2011)	51,950	5,126,653
Farms with NMS as a % of total livestock farms in Ontario	25%	-
Farms regulated by the NMA as a % of total Ontario farms	11%	14%

[53] Where livestock farms include: dairy cattle and milk production, beef cattle ranching and farming, including feedlots, hog and pig farming, chicken egg production, broiler production, turkey production, sheep and goat farming as well as horses and equine

Table 18: Convictions and Fines Resulting from AEOs use of the Referral to MOE's Investigations and Enforcement Branch Compliance Tool for Violations of the NMA, 2012 – 2016 (Ontario, 2016)

Date	Amount	Farm/NASM	Compliance Details	Location	Individual/ Company
21-01-16	$3,750	Livestock	Failure to comply with NMS – Barn distance	Peterborough	Individual
21-01-16	$40,000	Livestock	Manure spill	Brockville	Company
11-08-14	$9,000	Livestock	Interference with ministry survey and staff	Brantford	Individual
15-07-14	$18,000	NASM	Waste water treatment	Chatham-Kent	Company
25-04-14	$120,000	Livestock	Manure spill	Woodstock	Company
09-01-14	$3,500	Livestock	Interference with ministry survey and staff	Elgin Country	Individual
15-10-13	$1,200	Livestock	Manure management & no NMP	Strathroy	Individual
30-07-13	$4,000	Livestock	No NMP	South Dundas	Company
31-05-13	$28,000	NASM	Bio-solid storage	Branford	Company
17-05-13	$5,000	Livestock	Barn, manure management & no NMS	Dunnville	Company
03-10-12	$3,500	Livestock	Manure management & providing false information on NMS	Guelph	Individual
26-06-12	$2,000	Livestock	Improper animal disposal	Sault Ste Marie	Individual

5. Chapter 5: Summary, Implications and Recommendations for Further Research

The purpose of this thesis was to understand the factors that influence farmers' nutrient application decisions. To do this I review how nutrients move from the physical landscape to surface water, the role of nutrients in agriculture and the international agreements between Canada and the United States specifically targeting nutrients in the Great Lakes region. I empirically examined the factors that influence farmers' nutrient application decisions in the Gully Creek watershed, focusing on understanding explaining nutrient application decisions in excess of crop requirements. I compare the actual nutrient application rates to the recommend NMAN rate, and two alternative nutrient application rates, the yield maximizing rate and the gross margin maximizing rate. I assume that nutrients are risk increasing and if farmers are risk averse in their nutrient application decisions. I then assess the farm physical characteristics that influence the farmers' decision to apply nutrients in excess of the recommended NMAN rate using an OLS regression. Lastly, I discuss the enforcement of the Nutrient Management Act (NMA) by Ministry of the Environment and Climate Change (MOECC).

5.1. Principle Findings

1. Farmers in the Gully Creek watershed are, on average, applying nutrients at the recommended NMAN rate for nitrogen application in corn production, but not for nitrogen in winter wheat production, and phosphorus application in corn and winter wheat production.
2. Larger farms in the Gully Creek watershed are more likely to apply nitrogen and phosphorus fertilizer in excess of the NMAN rate for both winter wheat and corn production.

3. Fields with lower yielding corn and winter wheat are more likely to apply nitrogen below the NMAN rate, and in excess of the NMAN rate for phosphorus in winter wheat.
4. Fields with manure applications in corn production are more likely to apply nitrogen in excess of the NMAN rate, but below the NMAN rate for phosphorus. Fields with manure applications in winter wheat production are more likely to apply nitrogen below the NMAN rate.
5. The net phosphorus loadings at the watershed scale demonstrate how individual nutrient application decisions to apply in excess of crop requirements can multiply over a larger area.
6. Either famers required to meet the standards outlined in the NMA are complying to some acceptable level. Or, farmer compliance and MOECCs enforcement of the NMA is not viewed as a priority by the Ministry.

5.2. Contributions and Implications

This research was conducted in the Gully Creek watershed, studying the factors that influence the nutrient application decisions of 16 farmers. While the scale of the research study is limited, the findings have implications to the regulators and researchers focusing on nutrients in the Great Lakes region. These regulators and researchers include OMAFRA, the MOECC, conservation authorities, economists, and agronomists.

Farmers not regulated under the NMA are, for the most part, applying nitrogen but not phosphorus at the recommended NMAN rate. The net nutrient loadings at the watershed scale, specifically for phosphorus, demonstrates how small contributions can multiply over a large area. If phosphorus is the growth limiting nutrient controlling harmful algae blooms, OMAFRA, the MOECC and conservation authorities should focus on changing farmer nutrient application behavior. Larger farms and farms with lower yielding crops have an increased likelihood of over applying nutrients. To meet the internationally agreed upon reductions in nutrient loadings in the

Great Lakes region regulators should investigate targeting changing nutrient application decisions on farms with these characteristics.

The application of phosphorus in excess of the crop requirements occurs in both corn and winter wheat production. Phosphorus, unlike nitrogen, when applied in excess of crop requirements, can increase soil concentrations and be partially available to crops in the next year of production. Soil nutrient tests could be used to communicate to farmers the availability of phosphorus in the soil, and could decrease the application of phosphorus in excess of crop requirements. Emphasizing cost sharing programs that support soil nutrient testing, such as the Canada-Ontario Environmental Farm Plan, may decrease the excess phosphorus application I observed in the Gully Creek watershed.

Economists should not only be concerned with the costs imposed on society associated with the harmful algae blooms in Lake Erie, but also with the costs to the farmer associated with the excess application of nutrients. The application of nutrients in excess of crop requirements may incurs excess costs to the farmer. This excess cost, when linked to the lower yield observed in the research, could indicate a decrease in farm profitability and an opportunity for improvement. Decreasing the fertilizer application rate to the NMAN rate may result in an increase in farm profits. Economists and OMAFRA should investigate if decreasing the nutrient application rate to the crop requirement results in an increase in profit.

Agronomists, working privately or for government agencies, are responsible for advising farmers on how to improve soil productivity (increasing crop yields) (ASA, 2016). The findings of this research indicate that agronomists could decrease nutrient application rates in excess of the NMAN rate in a similar manner as discussed for OMAFRA, the MOECC and conservation authorities. Agronomists could decrease the advised nutrient application rate in lower yielding fields, as well as on larger farms.

5.3. Suggestions for Future Research

This thesis conducted an empirical economic analysis of farmers' nutrient application decisions in the Gully Creek watershed, in Southern Ontario. The Gully Creek watershed is a small watershed (1430 ha) within the Bayfield North watershed. The survey conducted by the Ausable Bayfield Conservation Authority (ABCA) included 16 farmers and accounted for 643.5 ha of the watersheds total area. The survey included historical land management decisions for the 2008 to 2010 period and predicted decisions for the 2011 to 2013 period. The predicted decisions were verified by windshield assessments conducted by ABCA. Future research should focus on expanding the empirical economic analysis to a greater area to confirm the findings within the Gully Creek watershed. This would require conservation authorities, like the ABCA, or government ministries, such as OMAFRA, to conduct surveys collecting farm nutrient management information. Conducting more regular surveys would also eliminate the use of predicted farm nutrient management information, and increase the rigor of the data. Expanding the economic analysis and confirming the finding from the Gully Creek watershed would further our understanding of factors influencing farmer nutrient application decisions in Ontario, and could be used to inform policy targeting nutrient loadings into surface water bodies.

The NMAN rate was assumed to be the the nutrient application rate that provided sufficient nutrient for crop growth while minimizing excess nutrient application. Verification of that thee NMAN rate actually meets crop requirements while minimizing excess nutrient application is merited. This would support the use of the NMAN rate as a rate that will decrease nutrient loadings in the Great Lakes region, enabling Ontario to meet target reduction goals.

The evaluation of the enforcement of the Nutrient Management Act (NMA) was limited by the availability of data for compliance and violations of the NMA. Information regarding the enforcement of the NMA by the Ministry of the Environment and Climate Change (MOECC) is limited to the publically available court bulletins for the criminal court of Ontario. Future research should focus on all levels of violations and all levels of compliance tools used by the MOECC.

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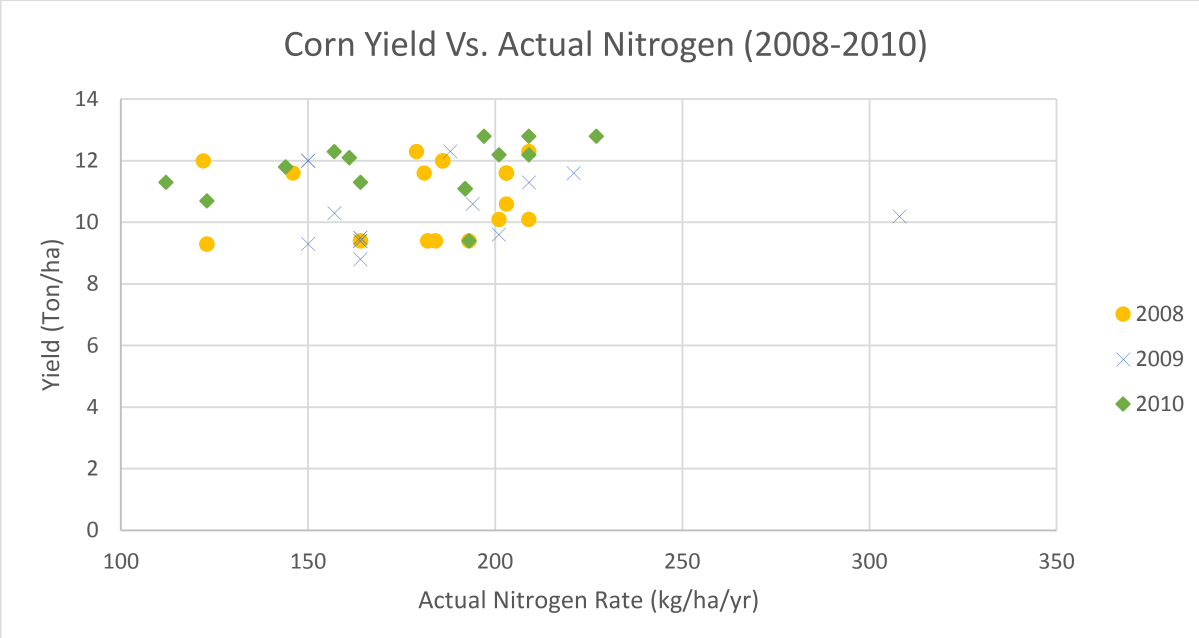
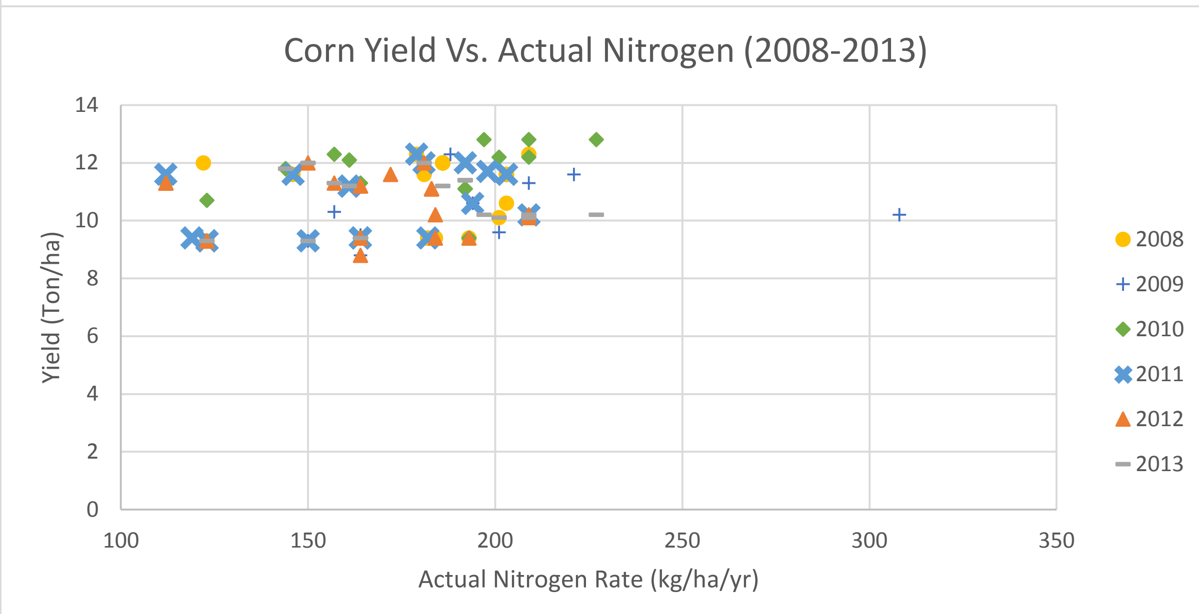
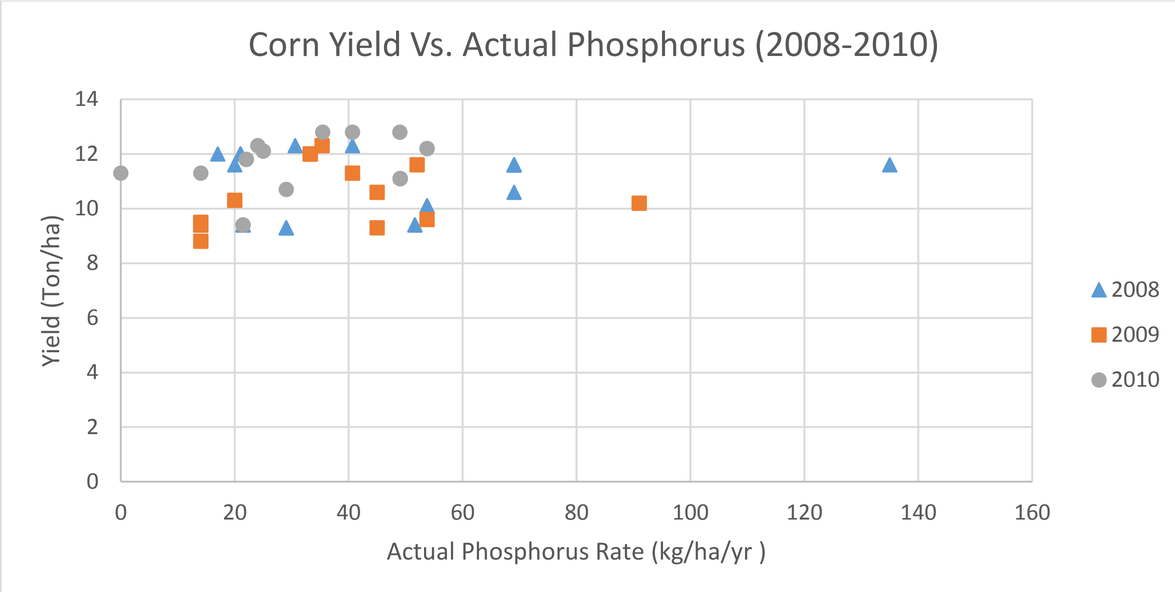
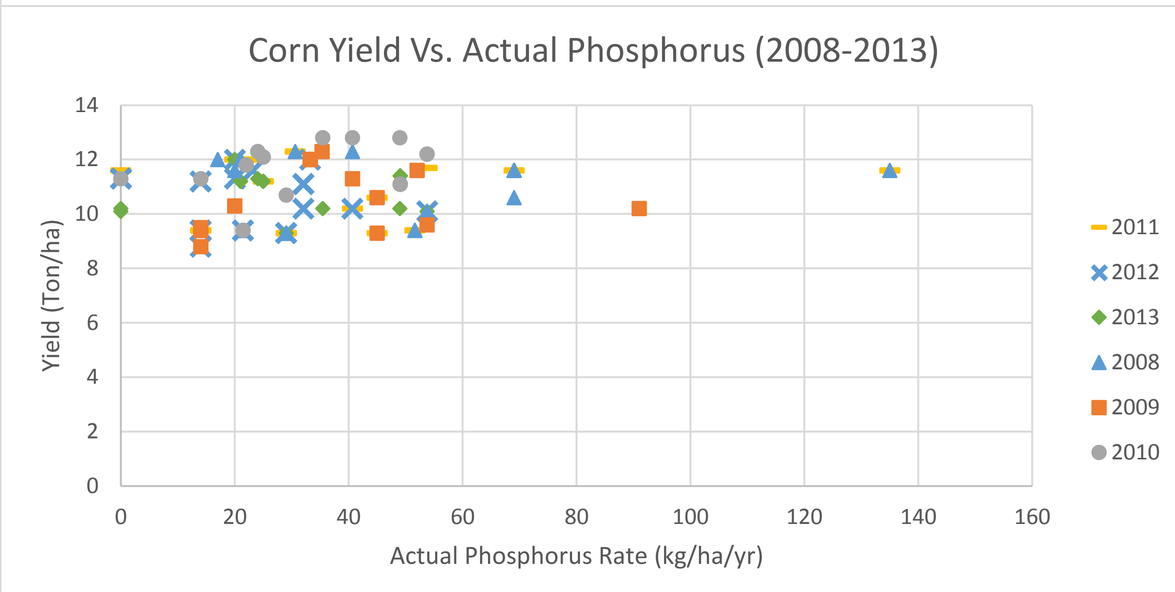
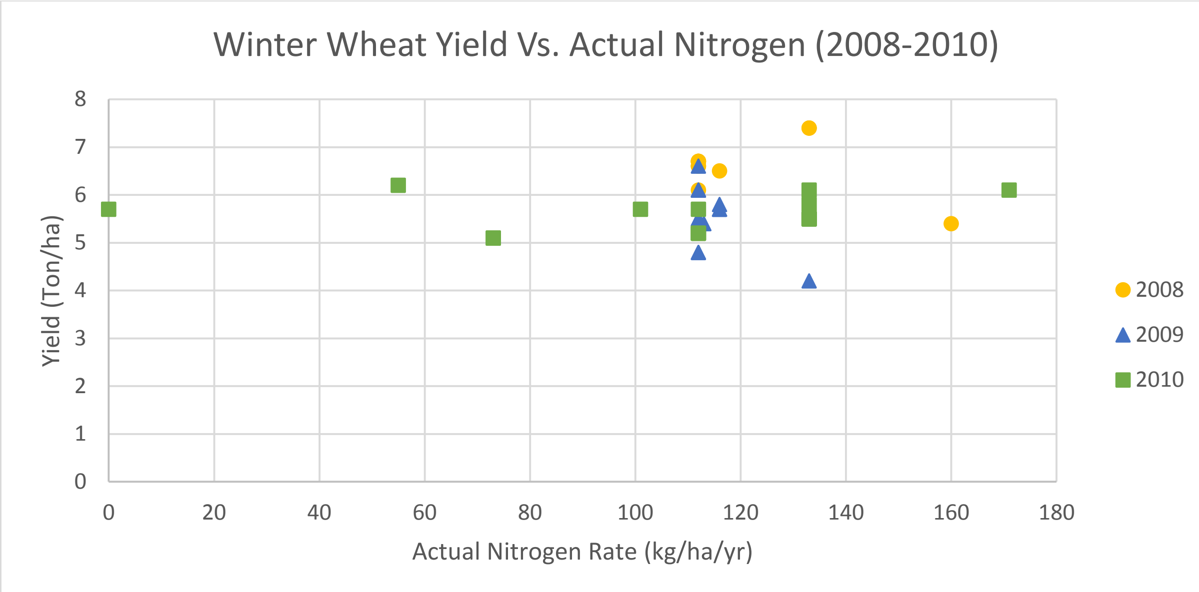
7. Appendix


Corn Yield Vs. Actual Nitrogen (2008-2010)
Yield (Ton/ha)
0
2
4
6
8
10
12
14
100
150
200
250
300
350
Actual Nitrogen Rate (kg/ha/yr)
2008
2009
2010

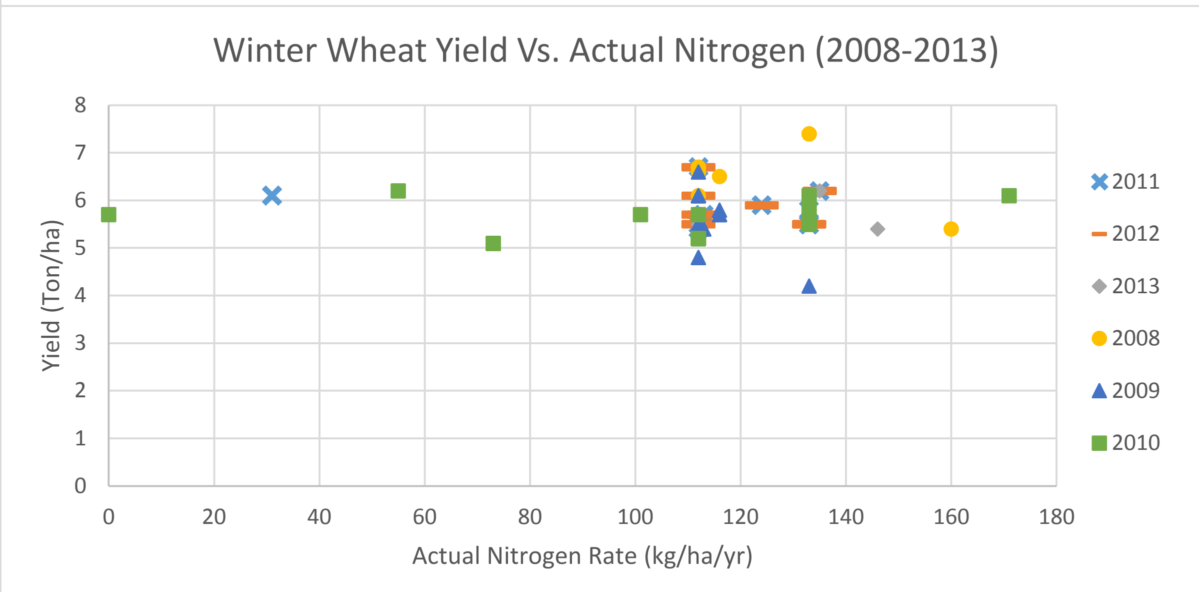

Corn Yield Vs. Actual Nitrogen (2008-2013)
Yield (Ton/ha)
0
2
4
6
8
10
12
14
100
150
200
250
300
350
Actual Nitrogen Rate (kg/ha/yr)
2008
2009
2010
2011
2012
2013


Corn Yield Vs. Actual Phosphorus (2008-2010)
Yield (Ton/ha)
Actual Phosphorus Rate (kg/ha/yr)
2008
2009
2010
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160


Corn Yield Vs. Actual Phosphorus (2008-2013)
Yield (Ton/ha)
Actual Phosphorus Rate (kg/ha/yr)
2011
2012
2013
2008
2009
2010
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160



Winter Wheat Yield Vs. Actual Nitrogen (2008-2010)
Yield (Ton/ha)
Actual Nitrogen Rate (kg/ha/yr)
2008
2009
2010



Winter Wheat Yield Vs. Actual Nitrogen (2008-2013)
Yield (Ton/ha)
Actual Nitrogen Rate (kg/ha/yr)
2011
2012
2013
2008
2009
2010

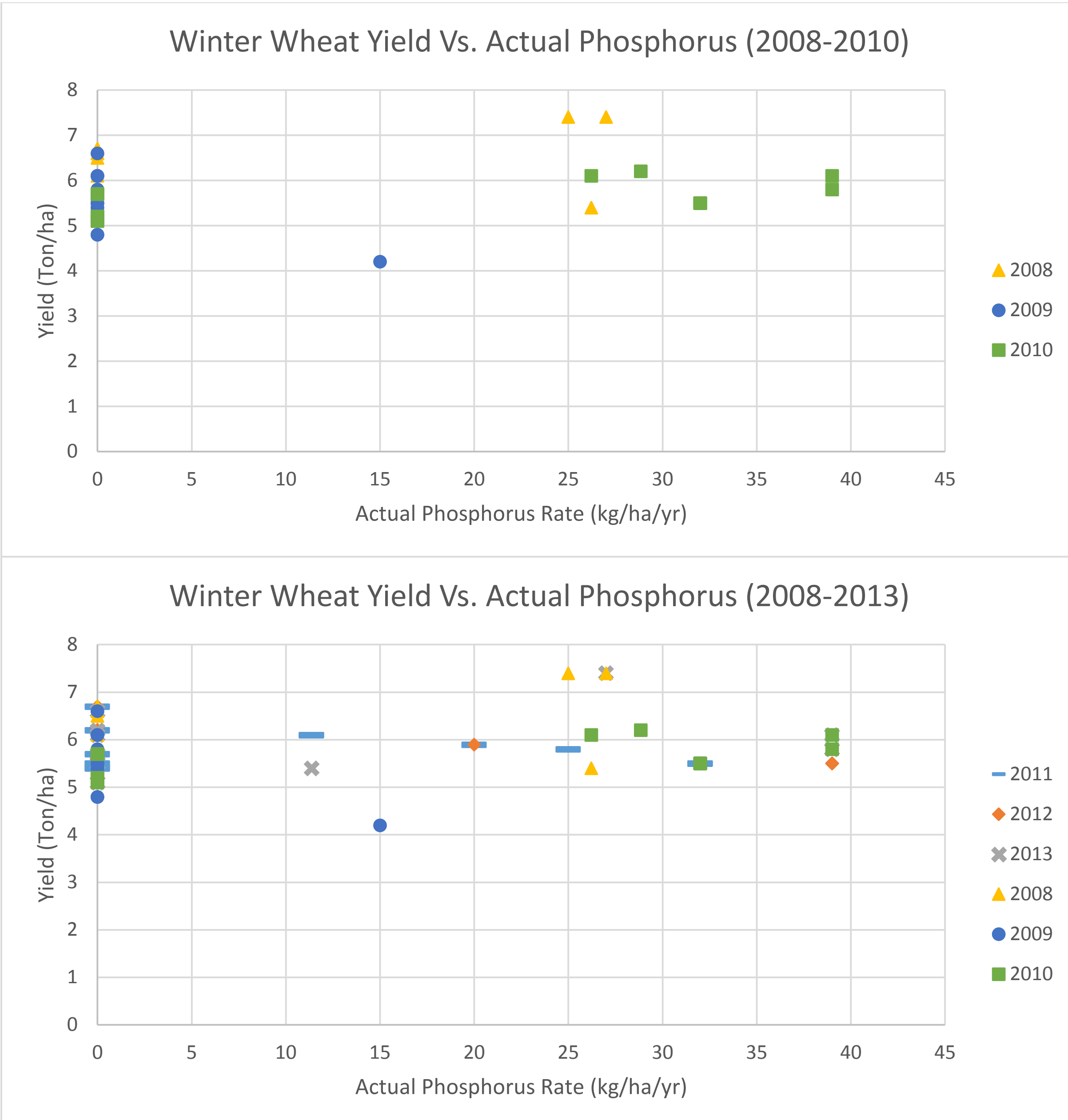


Figure 5: Actual Nutrient Application Rate (kg/ha/yr) Compared to Crop Specific Yield for Corn and Winter Wheat Production in the case of Nitrogen and Phosphorus, Across the Historical Observations (2008-2010) and Across the Entire Period of Observations (2008-2013)

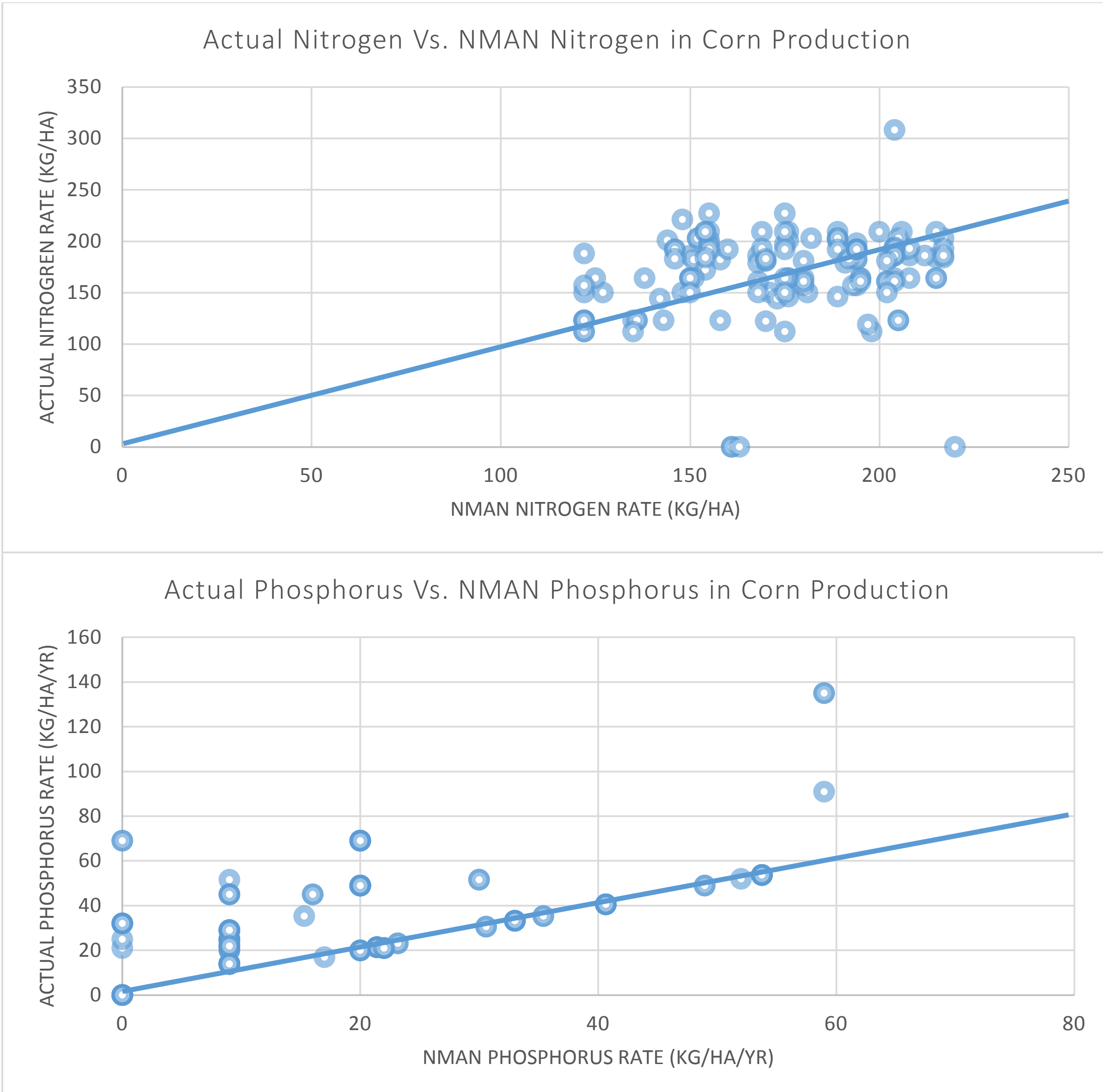


Figure 6: Actual Nutrient Application Rate vs. NMAN Application Rate in the Case of Corn Production for Nitrogen and Phosphorus

Note the clustering in the case of nitrogen, where there is an equal dispersion of observation on either side of the 45-degree line. In the case of phosphorus in corn production, no observation is below the recommended rate, there are a number of observations where the actual application rate is equal to the NMAN rate, but all other observation the $N_A > N_E$.

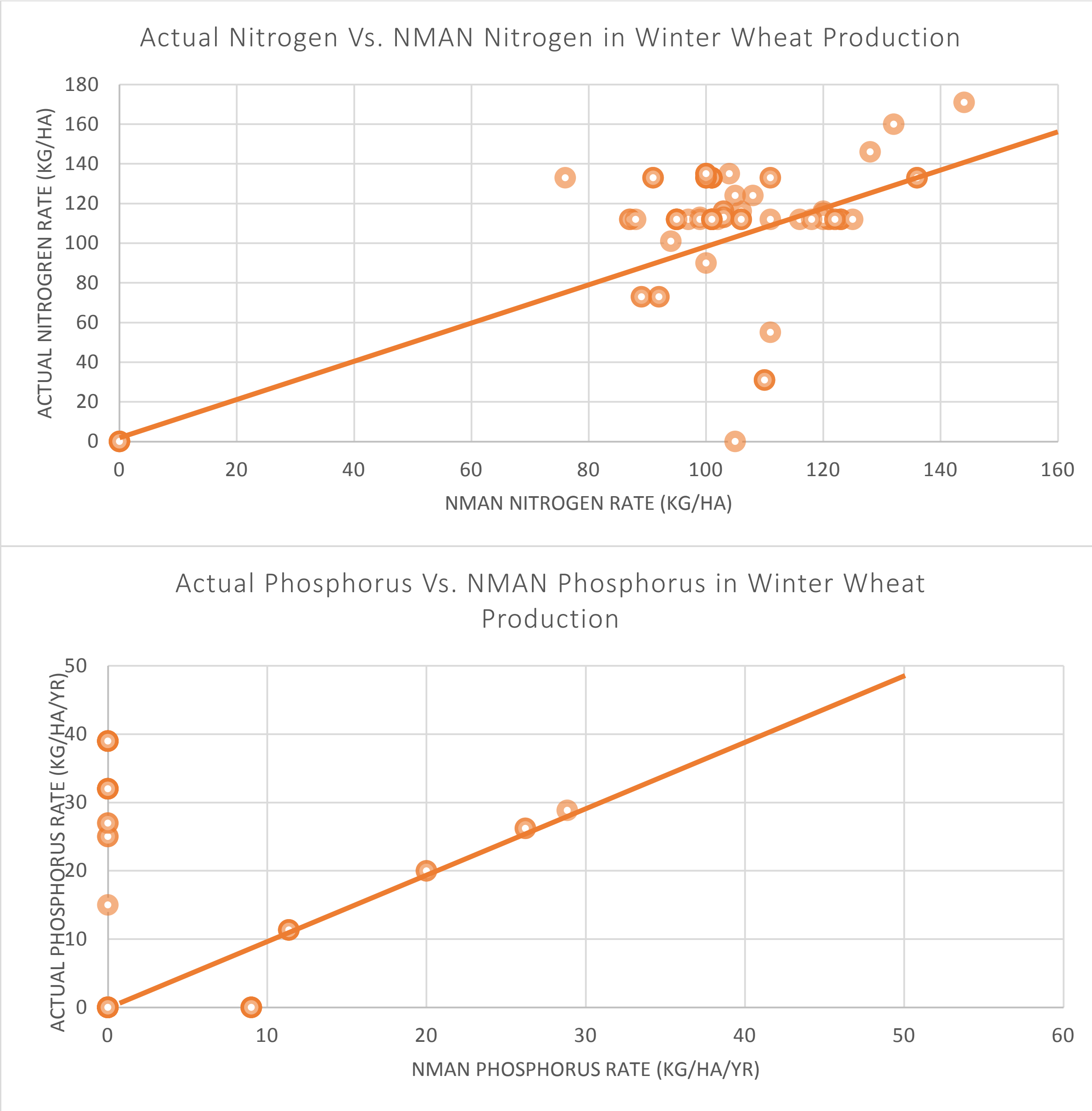


Figure 7 Actual Nutrient Application Rate vs. NMAN Application Rate in the Case of Winter Wheat Production for Nitrogen and Phosphorus

Note the common actual application rate in the case of nitrogen, clustering around 112 kg/ha/yr. Comparing to corn production, there is not the same level of dispersion, but much greater than that found in phosphorus in winter wheat. In the case of phosphorus in winter wheat production, there is a single observation below the recommended rate, a number of observations where the actual application rate is equal to the NMAN rate, but for the remainder of observations the $N_A > N_E$.